Korean Facilities and Instrumentation for Radio Astronomy

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Radio Technology group, TRAO, KVN group (KASI) & SRAO

EAO/JCMT instrument panel meeting, 8, Mar., ASIAA
- TRAO (Taeduk Radio astronomy Observatory) established in 1986, with cryogenic Schottky mixer
- 1990: 100/150 GHz SIS mixer receiver
- large MC survey with 15 beam array receiver since 2009; upgraded in 2015

| Site Information | East Longitude | 127° 22' 18.77"
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>North Latitude</td>
<td>36° 23' 53.17&quot;</td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>109 meters</td>
<td></td>
</tr>
<tr>
<td>Telescope</td>
<td>Primary Reflector Diameter</td>
<td>13.716 meters</td>
</tr>
<tr>
<td>Focal Ratio (f/D)</td>
<td>0.3704</td>
<td></td>
</tr>
<tr>
<td>Prime Focus</td>
<td>4.074</td>
<td></td>
</tr>
<tr>
<td>Cassegrain Focus</td>
<td>180 μm rms</td>
<td></td>
</tr>
<tr>
<td>Surface Accuracy</td>
<td>Elevation over Azimuth</td>
<td></td>
</tr>
<tr>
<td>Mount</td>
<td>Pointing Accuracy</td>
<td>&lt; 10° rms</td>
</tr>
<tr>
<td>Enclosure (Radome)</td>
<td>ESSCO LAM VI</td>
<td></td>
</tr>
</tbody>
</table>
upgraded TRAO 16 beam array

- Subreflector upgrade
- Servo upgrade
- Control computer upgrade

<table>
<thead>
<tr>
<th>SEQUOIA-TRAO</th>
<th>4X4 arrays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>85 - 115.6 GHz</td>
</tr>
<tr>
<td>FFT Spectrometer</td>
<td>125 MHz with 8192 channels</td>
</tr>
</tbody>
</table>

• Granted key science programs
  - C. W. Lee (TRAO Multi-beam Legacy Survey of Nearby Filamentary Molecular Clouds)
  - J. E. Lee (Mapping Turbulent Properties of Star-forming Molecular Clouds down to the Sonic Scale)
  - T. Liu (TRAO Observations of Planck cold clumps (TOP))

Sequoia-TRAO frontend
SRAO
(Seoul Radio astronomy Observatory)

- 1 million USD project initiated by SNU astronomy dept. from 1996
  plus additional collaboration fund granted from KASI
- **SRAO 6m telescope (2001-)**
  rugged structure suited for *mm-wave observation*
  replica antenna of BIMA array
  surface accuracy, drive system: **up to 300 GHz**
  200m elevation from sea level

Dec. 2007
SRAO 3mm Receiver (2000)

- RF frequency: 85-115 GHz
- DSB noise: 50 K
- 2002-2006

Components:
- Curved mirror M2
- Flat mirror
- Telescope beam
- Curved mirror M3
- Lens for image termination
- Quasi-optical sideband rejection filter
- SIS mixer block

SRAO (SNU) 6m telescope
- A wire grid adopted for polarization separation
- 2 mixer chips biased separately works for one polarization.
- LO signal generated from a WR-4 tripler is split for each pol. and further divided, coupled to each mixer chip. Separate attenuators adjust LO power to each polarization.
- USB IF output is amplified by a cryogenic LNA, with LSB terminated at each pol. (cf. sideband separation vs. sideband rejection)
SRAO 230 GHz Receiver (2008)

- RF frequency: 210–265 GHz
- Avg. SSB noise: 80 K (Tsys~150 K best in winter)
- Waveguide sideband rejection
- Dual polarization by wire grid
- Facility receiver: 2008-

- 1 GHz BW FFT spectrometer (Agilent)
  8 bit 2Gs/s, 61 kHz spec. resolution
KVN Yonsei Observatory

Slewing Speed ~ 3 deg/s

KVN Ulsan Observatory

KVN Tamna Observatory

\[ \theta_{HBPW} \approx 6 \text{ mas} @ 22 \]
\[ \approx 1 \text{ mas} @ 129 \]
KVN antenna

- D = 21m
- Shaped Cassegrain
- Main reflector
  - 200 panels
  - Four adjusters in each panel
  - Measured and aligned with photogrametry (at EL = 48deg)
- Sub-reflector
  - Controlled by Hexapod to compensate gravitational deformation
  - X,Y,Z,Tip,Tilt
# KVN Frontends

Band width = 256MHz

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>Tsys (K)</th>
<th>Aeff [Gain] (%) (Jy/K)</th>
<th>SEFD (Jy)</th>
<th>t_int (sec)</th>
<th>ΔS (5σ) (mJy/beam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>21.25-23.25</td>
<td>100</td>
<td>60 [0.078]</td>
<td>~1300</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Q</td>
<td>42.11-44.11</td>
<td>150</td>
<td>60 [0.078]</td>
<td>~1900</td>
<td>60</td>
<td>110</td>
</tr>
<tr>
<td>W</td>
<td>85-95</td>
<td>200</td>
<td>50 [0.062]</td>
<td>~3200</td>
<td>30</td>
<td>270</td>
</tr>
<tr>
<td>D</td>
<td>125-142</td>
<td>250</td>
<td>35 [0.043]</td>
<td>~6000</td>
<td>20</td>
<td>570</td>
</tr>
</tbody>
</table>

- Recording System (Mark6) : 4 x 512MHz
Phase Referencing for Tropospheric Compensation

Middelberg et al. 2005
Rioja&Dodson 2008,2011

“fast-frequency switching”
@ 22/43 GHz

< 5 deg.

Bright Reference Source

Weak Target Source

Weak Source & Astrometry

Credit by Rioja

Weak Source
Multi-Frequency Receiving System

• simultaneous Multi-frequency Observation
  – @ 22/43/86/129GHz
• dual Pol : LCP & RCP
  – simultaneous 2 freq bands w/ full stokes
• digital Backend : 256MHz BW (4 x 64MHz) , (4 x 512MHz in 2015)
Korea-Japan Correlation Center (KJCC)

- Daejeon Correlator
  - Joint Development & Joint Operation by KASI & NAOJ
  - Input Data Rate = 4 streams x 2Gbps x 16 stations
- DiFX Software Correlator
  - Linux Cluster
  - KVN only observation
combined VLBI array
KaVA (KVN and VERA Array)
Advantage: combined array
KVN SIS Mixer Chip (2010)

- RF frequency: 120-165 GHz
- $J_c \sim 5kA/\mu m^2$
- Junction diameter $\sim 1.6 \mu m$
- Quartz substrate
- Normal Nb tuning
- Fabricated in ASI AA

Superconducting junction details with RF tuning circuit
KVN 129 GHz Receiver Cartridge

- RF band: 124 - 142 GHz (band limited by circ. Polarizer)
- IF band: 8 GHz - 10 GHz (KVN system standard)
KVN 129 GHz Receiver Performance

RF frequency (GHz)

$T_{rx} (K)$

3-10 GHz IF(SSB)

4-6 GHz IF(DSB)
KVN 129 GHz Receiver Performance

**LSB**

**USB**

- **image rejection ratio (dB)**
- **RF frequency (GHz)**
KVN 129 GHz Receiver Performance

/home/KVN/Data/vfc//vfc315033.dat

/home/KVN/Data/vfc//vfc600909.dat
Phase shifter for circular polarizer
Orthomode transducer
Chronicles of ASTE FPA Development

- Sep., 2012 KASI started initial study on Korean participation in East Asia ALMA consortium
- June, 2014 ALMA/ASTE Development Workshop (NAOJ, Japan) → request for 300-500 GHz focal plane array for ASTE telescope by radio community
  ALMA-EA endorsement to development of similar FPA for ALMA TP array as future ALMA enhancement
- Aug., 2014 call for development proposal
  Korean participation in ALMA announced officially
- Nov., 2014 KASI submits a proposal for ASTE focal plane array
- Feb., 2015 Proposal accepted
- May, 2015- Dec., 2015: 1st- 4th KASI-NAOJ f2f meeting (Osaka, Japan)-will finalize scheduling and work scopes
**Instrument Overview**

45% wideband, compact focal plane array

- stacked Silicon feedhorn array pending test
- wideband Nb-AlN-Nb SIS mixers (NAOJ lead fabrication)
- balanced sideband separation configuration
- low-power consumption cryogenic LNAs (~1mW, 39 dB, 2K noise)
- 8 GHz digitizer+ GPU-based FFT spectrometer (with polyphase digital filter & ring buffer)
- Single pixel engineering model delivery ~2017
  4 pixel FPA delivery ~ 2019
- Proposal to ALMA board for TP array receiver ~ 2020
Focal Plane Array for TP array: Testbed at Chile, ASTE Observatory

What is ASTE?

- Diameter: 10m
- Surface accuracy: 19μm
- Main beam efficiency: 0.6-0.7@850μm
- Pointing accuracy: 2" rms
- Beam size: 22" @850μm
- Remote observation

- Initial feasibility study on 300-500 GHz receiver architecture: 2015
- Proof of concept: single-pixel cartridge: Q2 2017
- 4 pixel cartridge: Q2 of 2019
## Specification of ASTE FPA

<table>
<thead>
<tr>
<th>Specifications</th>
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<tbody>
<tr>
<td>Number of focal plane pixels</td>
<td>4 pixels (min.) for ASTE cartridge cryostat</td>
</tr>
<tr>
<td>Operation RF frequency</td>
<td>300-500 GHz (nominal 45% fractional BW)</td>
</tr>
<tr>
<td>Receiver noise temperature</td>
<td>&lt;70 K(300-370 GHz), &lt;130 K(385 GHz-500 GHz)</td>
</tr>
<tr>
<td>IF frequency</td>
<td>4-8 GHz (USB, LSB)</td>
</tr>
<tr>
<td>Spectrometer BW/channel width</td>
<td>4 GHz/7.6 kHz</td>
</tr>
<tr>
<td>Polarization</td>
<td>dual polarization using waveguide OMT</td>
</tr>
</tbody>
</table>

![Graph showing transmission vs frequency]
Focal Plane Array: blocks for balanced mixers

A strawman half-block layout of balanced sideband-separation mixer: block fits within 14(W)mm X 14(H)mm. (This is a prior design to OMT version)
We indeed considered *possible component sizes* for this layout.

OMT: double ridge type with additional E-bend.
GPU spectrometer for ALMA TP array

• Development background
  – One of the Korean contribution to the ALMA project
  – Sub-array mode of 7m and TP arrays of the ACA hasn’t operated.
  – No full polarization has been done using the TP array
  – Spectrometer for a future multi-beam receiver of the TP array

• Requirements: current ALMA spec
  – Input data rate/antenna: 2 GHz x 4 BB x 2 pol x 3 bit x 2 Nyquist = 96Gbit/sec
  – Full polarization, …
The “kfftspec” Spectrometer

- Multi-GPU cross-power spectrometer for nVidia GPU
- Development setup
  - Dell PowerEdge T630, nVidia Tesla K40m, 2 x TITAN X
  - Sample data from file or 10G/40G (KVN; 2-bit)

- Possible ACA spectrometer rack setup
  - Four to eight GPU in each node, 1-2 nodes per band
  - Sample data from “OC-192” (ALMA; 3-bit) via DXRP PCIe board

Jan Wagner’s slide
- Sample data are in “VLBI Data Interchange Format”
- Segmentation is based on VDIF frame timestamps
- Segments are distributed to GPUs in round-robin fashion, to N graphics cards, with M CUDA ‘Streams’ on each (N x M)
- All CPU and GPU processing is running asynchronously
- All GPU data transfers (DMA) are asynchronous, results are copied out while new data are copied in

Jan Wagner's slide
• TRAO, SRAO, KVN system have been introduced but tried to focus on KVN engineering researches.
• Brief introduction to commenced ASTE FPA project as Korean ALMA-EA contribution to future ALMA enhancement