P86

A new “off-point-less” method for mm/submm spectroscopy with a frequency-modulation local oscillator

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We have been developing a new method for mm and submm spectroscopy with a *frequency-modulation local oscillator* (FMLO), which adds a new powerful option to the conventional schemes such as the *position-switching* and *frequency-switching* methods. The FMLO method has a potential to dramatically improve the sensitivity of single-dish spectroscopic observations, by just changing the way of controlling the receiver system. The noise removal technique that the FMLO method employs is similar to that used in continuum deep surveys and CMB cosmological experiments using multi-pixel bolometer cameras; If we consider the one-to-one relations between multibeam imaging observations and spectroscopic one, “pixels of a camera” → “channels of a spectrometer” and “rapidly moving the field of view” → “quickly changing the observing frequency (with a FMLO)”, then the technique can be applied to spectroscopic observations. We have implemented a new FMLO control system on the ASTE 10-m telescope, which demonstrates that the FMLO method does work for (1) minimizing the overheads and maximizing the observing throughput, (2) removing of $1/f$-type correlated noises, (3) removing spectral baseline ripples, and (4) separating sidebands, as shown in Figure 1.

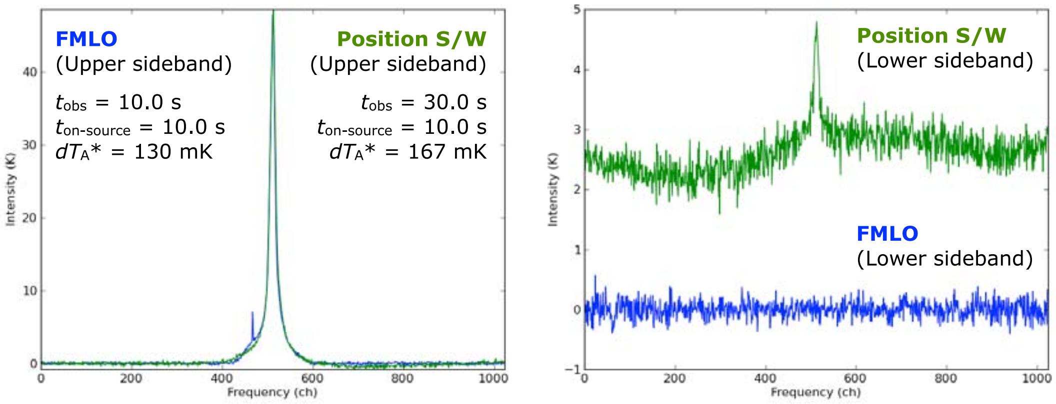

Figure 1: ***(left)*** The 345 GHz upper sideband spectra of ^{12}CO (3–2) toward the Ori A molecular cloud taken with the FMLO (blue curve) and position-switching (PSW) methods (green curve) implemented on ASTE, which demonstrates that the FMLO spectrum is 2.2× more sensitive than PSW for fixed total observing time ($t_{\rm obs}$) including any overheads, and is 4.9× more efficient than PSW for fixed noise level ($dT_{\rm A}^{*}$). The band width and frequency resolution are 512 MHz and 0.5 MHz, respectively. A spike seen in the red wing is presumably a ^{12}CO (3–2) in the Earth’s stratosphere. ***(right)*** The 333 GHz lower sideband spectra across the image sideband of ^{12}CO (3–2) shown in the left panel. While the spectrum taken with the PSW method is by the CO line leaking from the upper sideband and baseline fluctuations, that taken with the FMLO technique provides a fairly flat baseline with no contamination of the image sideband since frequency modulation smears out image-sideband line features.

P87

A New 45 GHz Band Receiver with Dual Polarization for NRO 45-m Telescope

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Write your abstract here. We are currently developing the 45 GHz band, dual polarization receiver to be mounted on a Nobeyama 45 m radio telescope. In this presentation, we report on the current status of development of the new dual polarization receiver. In the process of star formation, the magnetic field is considered to play an important role. However, our understanding of the importance of magnetic field in star formation is only poorly understood because of the lack of the accurate measurement of the magnetic field strength in molecular cloud cores. To shed light on the issue of the magnetic field, we plan to directly measure the magnetic field strength using the Zeeman effect of a molecular line, CCS ($J_N = 4_3 - 3_2$) which is abundant in the pre-protostellar phase. However, the Zeeman shift is anticipated to be around 60 Hz, and therefore Stokes V is so weak, about 0.3 % of I at narrow line width of 0.3 km s^{-1}. For this purpose, a receiver capable of receiving two circularly polarized waves with high sensitivity is the key to success this project.

In development of cooled receiver, optics and polarization splitter are required. First, we designed an optical system for guiding the condensed signals at the antenna to the receiver. As much as possible by increasing the size of the metal mirror used in the optical system, we have to reduce the spillover loss. Moreover, to minimize the beam angle bend in the ellipsoidal mirror, achieving low cross polarization coupling. Second, separating polarization, we design an orthomode transducer (OMT). As a result of measurement, the OMT performed return loss of less than 20 dB, cross polarization coupling of better than 30 dB and insertion loss of less than 0.3 dB across the observational band. For future, we will install a cooled receiver to 45m radio telescope, we will try the polarization observation.

P88

Optimization by Smoothed Bandpass Calibration in Radio Spectroscopy

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We have developed the Smoothed Bandpass Calibration (SBC) method and the best suitable scan pattern to optimize radio spectroscopic observations. Adequate spectral smoothing is applied to the spectrum toward OFF-source blank sky adjacent to a target source direction for the purpose of bandpass correction. Because the smoothing process reduces noise, the integration time for OFF-source scans can be reduced keeping the signal-to-noise ratio. Since the smoothing is not applied to ON-source scans, the spectral resolution for line features is kept. An optimal smoothing window is determined by bandpass flatness evaluated by Spectral Allan Variance (SAV). An efficient scan pattern is designed to the OFF-source scans within the bandpass stability timescale estimated by Time- based Allan Variance (TAV). We have tested the SBC using the digital spectrometer, SAM45, on the Nobeyama 45-m telescope. The optimal smoothing windows were determined as 501, 28, 18, and 4 ch for bandwidths of 2000, 500, 125, and 15.6 MHz, respectively. The optimal scan pattern was designed as sequences of [60-s ON + 10-s OFF] and [48-s ON + 16-s OFF] scan pairs for narrow and wide bandwidth, respectively. The noise level with the SBC was reduced by factors of 1.8 and 1.3 compared with the conventional method. We also found sporadic instability (bursts) in the total power and spectra in IF during the test observations. Although the bursts significantly distorts the resultant spectra, we found a solution to cancel the spectral variation by decomposing them into static and burst components. This solution can be a hint to ease spectral flagging processes and to bring better efficiency in integration time.

P89

ALMA Extended Array

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We propose to append five 12-m antennas within 300-km to realize high angular resolution of < 1 mas and sensitivity to detect $T_{\rm b} < 1000$ K. This ALMA extended array offers a new parameter space of “Thermal universe with VLBI resolution”. Proposed science case includes black-hole formation in sub-mm galaxies, mass accretion processes onto protostars, imaging stellar photospheres, distance measurements of stars, and so on. The array also functions as a part of sub-mm VLBI that targets black- hole imaging, and contributes to establish technologies on sub-mm coherence that is critical for the ALMA enhanced array. In the symposium we discuss about technical and practical issues to realize the plan.

P90

Polarization calibration plans for single-dish radio observations

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We report our polarization calibration plans for single-dish radio telescopes. Polarization observations offer unique astronomical properties such as magnetic fields and plasma composition. To measure polarization properties, dual polarization signals such as right- and left-hand circular polarizations, must be received individually. Since cross talk and delay between orthogonal signals affects accuracy in polarization measurements, detailed calibration plans are crucial. We propose a polarization calibration plan using a digital cross correlator between orthogonal polarizations, a digital spectrometer. An absorber covering the feed horn is used as a delay calibrator and also as an unpolarized source. Test observations were performed using the VERA Mizusawa station at 22 GHz. We observed absorber, unpolarized sources (Jupiter, 3C 84, and NGC 7027) and some linearly polarized sources (3C 286, 3C 345, 3C 279 and Orion KL) in various parallactic angles and field rotator angles. We applied delay calibration by using cross correlation function toward absorber. We decomposed into the optics-originated and electronic D-term by using different phase responses between right- and left-hand circular polarizations. And we estimated the polarization degree of the outbursting water maser of Orion KL as 58.6%. In our talk we will present our calibration processes and polarization performances for single-dish observations.

P91

ALMA Science Verification in the EA Imaging Team

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I will summarize in this talk the Science Verification (SV) process used to demonstrate that ALMA data is valid. The list of SV sources was designed to achieve interest in the whole astronomical community, from protoplanetary systems such TW Hya to the BR1202 high-z system, and the data is regularly released for public use via the ALMA science portal in http://almascience.nao.ac.jp/alma-data/science-verification. I will focus my presentation on SV projects where the East Asian Imaging team (including NAOJ and ASIAA) has had a direct contribution in the observation design, data reduction, and validation, in collaboration with the Joint ALMA Office, North America and European Imaging Teams. These include main array interferometric data of IRAS 16293 at band 9 (multiple lines), Antennae galaxies CO(2–1) and CO(3–2), NGC5128 CO(2–1), and BR1202 CII and band 7 continuum data. I will also present the demonstration on the new Cycle 1 capability of zero and short spacings obtained using the Atacama Compact Array (ACA), and its combination with data obtained with the main array. During the talk I will review some exciting scientific results recently obtained with these SV data that had not been previously been detected due to lack of sensitivity/resolution in previous observations, such as a newly discovered molecular arm likely of tidal origin in the south of the Antennae galaxies.

P92

Astronomical Verification for ALMA Array Element

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The ALMA System Integration Science Team (SIST) is a group of scientists and data analysts whose primary task is to verify and characterize the astronomical performance of array elements (individual, fully equipped antennas) as single dish and interferometric systems.

The full set of tasks is required for the initial construction phase verification of every array element, and these can be divided roughly into fundamental antenna performance tests (verification of antenna surface accuracy, basic tracking, switching, and on-the-fly rastering) and astronomical radio verification tasks (radio pointing, focus, basic interferometry, and end-to-end spectroscopic verification). These activities occur both at the Operations Support Facility (OSF: just below 3000 meters elevation) and at the array operation site (AOS) at an elevation of 5000 m above sea level.

P93

3-d modeling of interferometric data cubes

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ALMA, and other instruments planned in the next decade, will produce data cubes with high spectral and spatial dynamic range. For many sources, this now permits or even demands more sophisticated modeling with 3-d radiative transfer tools. We describe a pipeline we have created to do this in a semi-automated fashion, and illustrate this with modeling results of SMA and HIFI data of SgrB2.

Antenna Surface Measurements Using Astronomical Sources

SAMANTHA KAJ BLAIR[1], RICHARD HILLS, AND ROBERT LUCAS

[1] ALMA

wavelength of the incoming signal in order to collect signals with high efficiency. For observations at sub-millimeter wavelengths it is therefore critical to have extremely accurate means of measuring antenna surfaces and for monitoring their deformations under a range of conditions.

We have made measurements of the surfaces of the ALMA antennas using signals from astronomical sources, typically bright quasars. We are able to employ the full power of the interferometer array for this purpose, using some of the antennas to provide phase and amplitude reference signals while scanning the antennas under test in a raster pattern. Fourier inversion of the resulting measurement of the complex beam pattern yields a map of the errors in the wavefront at the aperture. We call this method ”astro-holography” in order to distinguish it from holographic antenna measurement techniques using man-made transmitters. Astroholography has many advantages over other techniques: the signals that are being used to measure the accuracy of the surface are the same as those for which the antenna is going to be used in operation; the entire system (main reflector surface, the secondary mirror, receiver and membrane) are all included, and these measurements also give information about the alignment of the optics; and the measurements are being made under the real conditions that will encountered in practice including varying elevation angle, temperature and thermal radiation.

The poster will present data showing that, under very good conditions, the repeatability in the measurements can approach the level of 1 micron rms. It will also demonstrate that the deformations in the surface due to gravity are easily detected and that other changes, probably due to thermal effects are also seen.

P95

ALMA Science Verification results

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P96

The Japanese VLBI Network

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A VLBI network, called the Japanese VLBI Network (JVN) has been established in Japan since 2005 (JVN Web Site, http://www.astro.sci.yamaguchi-u.ac.jp/jvn/). The JVN consists from 13 telescopes; the VERA (NAOJ), Tomakomai 11m (Hokkaido university), Gifu 11m (Gifu university), Yamaguchi 32m (NAOJ, Yamaguchi university), Kashima 34m (NICT), Tsukuba 32m (GSI, Tsukuba university), Usuda 64m and Uchinoura 34m (ISAS/JAXA), and Ibaraki 32m (NAOJ, Ibaraki university). Six of the thirteen telescopes are connected with a high-speed (2Gbps) e-VLBI network based on the SINET4 by National Institute for Informatics (NII). The JVN is operated under cooperation of NAOJ and seven universities in Japan, with supports from ISAS/JAXA, NICT and GSI. The length of baselines ranges from 50 km (Kashima - Tsukuba) to 2500 km (Tomakomai - VERA Ishigaki).

We show two of scientific results obtained with the JVN. Some class of AGNs with relatively low flux density (mJy level), such as narrow-line Seyfert 1 galaxies (NLS1) and broad absorption line quasars (BAL quasar), have been observed and studied with the JVN. Some sources of these classes exhibit relatively high Doppler boosting, although these classes of AGN are tend to be radio-quiet (Doi et al. 2007, Doi et al. 2009). Methanol maser at 6.7 GHz is one of the main targets of the JVN. A VLBI observation of Cepheus A (Cep A) revealed the elliptical distribution of the maser spots around a high-mass young stellar object (HW2) (Sugiyama et al. 2008). We have made a monitoring observation of Cep A and detect the internal motion of the maser spots; the motion was a combination of the rotation and infalling motion toward the central star.

We think that it is important for JVN to collaborate with countries of east-Asia; Korea, China and Taiwan. To combine the JVN with their own networks (KVN and CVN), a powerful VLBI network will be constructed as East-Asian VLBI Network (EAVN). Test observations have been started and preliminary images are already obtained.

References

Doi, A. 2007, PASJ, 59, 703
Doi, A. 2009, PASJ, 61, 1389
Sugiyama, K. et al. 2008, PASJ, 60, 1001

P97

VLBI Monitoring Programme of AGN Jets in Japan and Future Prospects for Mm/submm VLBI

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*

The location of high energy emission and its production mechanism are long standing problem in the physics of active galactic nuclei (AGN) jets. While a number of competing models have been proposed, the γ-ray emission mechanism and the location of emitting region are still disputed. Quasi-simultaneous multiwavelength study is a key to discriminate such models. Here we present an intensive VLBI monitoring programme towards the AGN jets, so-called GENJI programme. Currently, we are monitoring 8 notable AGNs including different subclass of AGN (flat spectrum radio quasars (FSRQs), BL Lacs, and radio galaxies) once per two-weeks using VERA at 22 GHz (Fig. 1). Typical angular resolution is about 1 milli-arcsec, which allows us to resolve the central pc-scale region in the nearby AGNs. We have successfully coordinated follow-up observation right after the γ-ray flares in three AGN (3C 454.3, NRAO 530, and PKS 1510-089). The radio core, which is identified as the brightest point on the VLBI image, shows flux increase at 22 GHz some time after the γ-ray flare. This delayed flux increase in radio band indicates that the γ-ray emitting region is presumably opaque at this frequency range. On the other hand, it is reported that mm/submm light curve shows a good correlation with the γ-ray flare particularly in 3C 454.3. Mm/submm VLBI is a promising method to probe the γ-ray emitting region directly and will give a strong constraint on the physics of high-energy emission and particle acceleration. Phase-up ALMA will be a key technique to achieve the mm/submm VLBI.

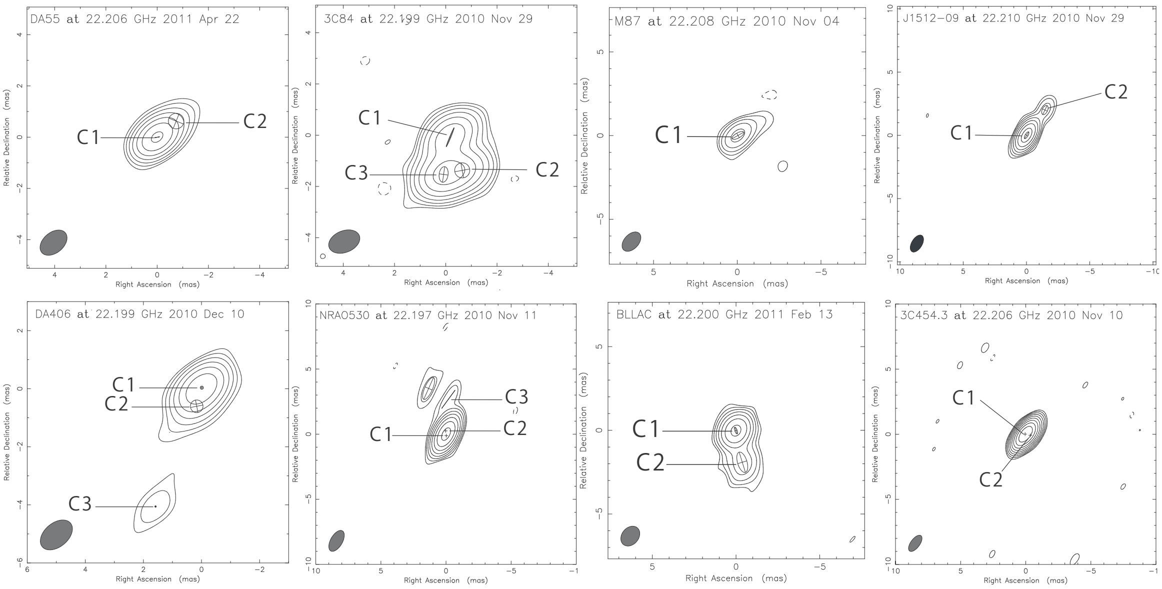

Fig. 1: Contour plots of total intensity of GENJI sources at 22 GHz.

P98

Development of 32-m Radio Telescopes for Monitoring Observations of Methanol Masers, H_2O Masers, and Radio Continuum

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H. Ogawa[2], K. Fujisawa[3], K. Sugiyama[3], K. Motogi[3], H. Takaba[4], K. Sorai[5], N. Nakai[6],
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Star formation is frequently accompanied with masers and radio continuum emission with strong variability. Class II methanol masers (including 6.7 GHz) are one of the best probe to study the environment around massive young stellar objects such as disk and outflow. H_2O masers are also used to probe jet and/or outflow. Monitoring observations of the intensity and velocity are already made by several groups (e.g., Goedhart et al. 2004; Fujisawa et al. 2012), but the observing intervals are one day or more. More frequent observation will reveal the activity associated with smaller scales.

Takahagi and Hitachi 32-m antennas, which have been used for satellite communications at 4 and 6 GHz by KDDI, were decommissioned in March 2007. These antennas were transferred from KDDI to NAOJ in January 2009, and now belong to the Ibaraki station, which is a branch of Mizusawa VLBI Observatory of NAOJ. We, NAOJ and Ibaraki University, in cooperation with other institutes such as ISAS/JAXA, NICT, GSI, and universities (Hokkaido Univ., Univ. Tsukuba, Gifu Univ., Osaka Prefecture Univ., Yamaguchi Univ., and Kagoshima Univ.) have decided to use these antennas for VLBI network (Japanese VLBI Network: JVN; East-Asia VLBI Network: EAVN). We will use these antennas not only for VLBI observations but also for single dish and 2-element interferometric observations.

We are using the cooled receiver systems covering 6.5–8.8 GHz, whose system noise temperature was measured to be $\sim$20 K, including atmosphere toward zenith, and the room-temperature 22 GHz receiver, whose system noise temperature including atmosphere toward zenith was $\sim$250 K. We are now developing cooled receiver system at 22 GHz. The pointing accuracy is $\sim$0.4 arcmin, which is measured by the observations of strong radio continuum sources such as 3C273 at 8 GHz. The aperture efficiency is measured to be 55–75 at 6.7 and 8 GHz, and $\sim$30% at 22 GHz. The spectrometer system using K5/VSSP32 was installed for single dish observations (Fig. 1). We succeeded first scientific VLBI imaging observations at 6.7 GHz in August 2010, with 6 antennas (VERA×4, Shanghai, and Hitachi) participated (see the presentation by K. Sugiyama et al.). We also achieved "first fringe" in June 2012 between Takahagi and Tsukuba at 22 GHz using IP-VLBI system. We are now testing two-element array using Hitachi and Takahagi antennas (Fig. 2). We acknowledge NICT for the use of correlation software.

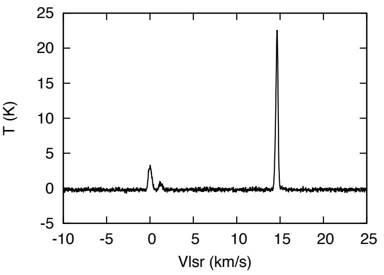

Fig. 1. Sample spectrum of 6.7 GHz methanol maser toward ON1 obtained at Hitachi telescope. Integration time is 10 min. and sampling is 4 bit.

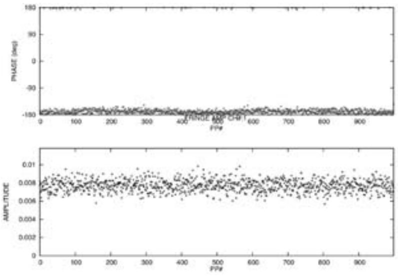

Fig. 2. Fringe phase and amplitude obtained by the Hitachi-Takahagi two-element array toward NRAO512 at 6.660–6.676 GHz (10 min, 4 bit).

References: Goedhart, S. et al. 2004 MNRAS, 355, 553; Fujisawa, K. et al. 2012, PASJ, 64, 17

P99

Test observations of a new 100 GHz wave-band FOur-beam REceiver System on the Nobeyama 45-m Telescope (FOREST)

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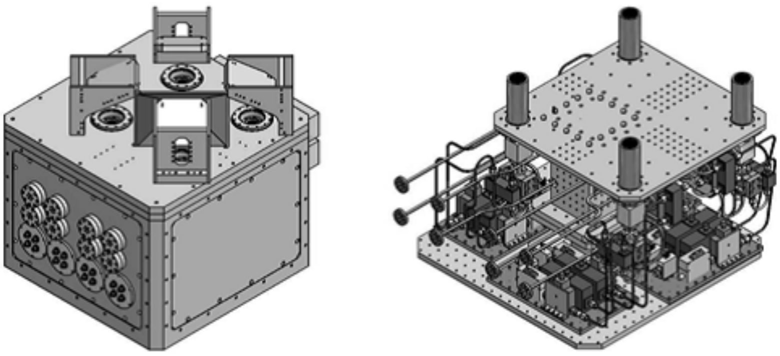
We report results of test observations of a new 100 GHz wave-band FOur-beam REceiver System on the Nobeyama 45-m Telescope (FOREST) from 2012 April to June.

The FOREST consists of four waveguide-type dual-polarization sideband-separating SIS mixer receiver systems of 100 GHz wave-band. Thus, the FOREST uses eight 2SB mixers and has 16 intermediate frequency (IF) outputs in total. A configuration of 4 beams is a quadrate of 2×2, and a separation of 2 adjacent beams is designed to be $\sim 50\,''$. IF bands are set to 4.0 – 8.0 GHz in the lower sideband (LSB), but set to 4.0 – 12.0 GHz in the upper sideband (USB) in order to observe C^{18}O($J = 1 - 0$) line at 109.78 GHz, ^{13}CO($J = 1 - 0$) line at 110.20 GHz, and ^{12}CO($J = 1 - 0$) line at 115.27 GHz simultaneously.

We installed the FOREST on the 45-m telescope in 2012 March, and started test observations from the next month. The tentative receiver noise temperatures were 70 – 200 K in single sideband, and the image rejection ratios (IRRs) were typically 5 – 10 dB at the radio frequency of 110 GHz. First, we determine the optimum position of the sub-reflector for the FOREST by observing continuum emission of the Saturn. Secondary, we obtain the beam pattern of the antenna for each beam by observing the SiO maser at 86 GHz in LSB. The measured beam separation is $51''.7$, which is consistent with the optics design, and we found no major deformation of the beam pattern. Thus, we judged that the mapping with the FOREST can be performed without any incident. Finally, we successfully obtained $7' \times 7'$ on-the-fly maps in C^{18}O($J = 1 - 0$), ^{13}CO($J = 1 - 0$), and ^{12}CO($J = 1 - 0$) line emission of the standard source, W 51, simultaneously with all the 4 beams.

Through the test observation, we got an important foothold in the scientific observing run of the FOREST from 2013 although we have to solve remaining problems as follows: (1) performance upgrade of 2SB mixers (receiver noise temperature, IRR, etc.), (2) improvement of band characteristics in USB, and (3) construction of a rapid receiver tuning system.



Appearance and alignment of components of the FOREST designed with 3 dimension CAD platform.

P100

The Greenland Telescope (GLT) Project
— For submm VLBI and THz astronomy —

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Using an ALMA prototype antenna, we have been deploying a submm and THz observing telescope at the summit on the Greenland ice cap. The primary target of this Greenland Telescope (GLT) is to identify a shadow image of Super Massive Black Hole (SMBH) with Very Long Baseline Interferometry (VLBI). The site selection was done based on the following criteria: (1) to produce longer baselines with existing and planned submm telescopes, and (2) to have high sky transparency at submm and higher frequencies.

The GLT gives longer baselines with the existing submm telescopes. In particular, the summit is 3,200 m high and temperature goes down to -70°C. Together with ALMA in Chile and SMA in Hawaii, the GLT forms an excellent triangle to observe M87, one of the most promising targets to figure out the shadow image. Phase-up ALMA will give high sensitivity to the triangle, performing a key triangle at 345 GHz with the angular resolution of 20 μ arcsec. As the GLT produces longer North-South baselines, it also provides a great opportunity to investigate the prominent jet of M87.

By the radiometer monitoring at 225 GHz, the summit site is shown as one of the best sites for submm and THz observations on the Earth. For one year monitoring of the opacity, the sky opacity is shown to be comparable to that of ALMA and the South Pole Telescope, as seen in Figure 1. The single dish operation is planed as the observation time for VLBI is not dominant. We are planning to install single dish instruments like bolometer arrays and multi feed heterodyne receivers.

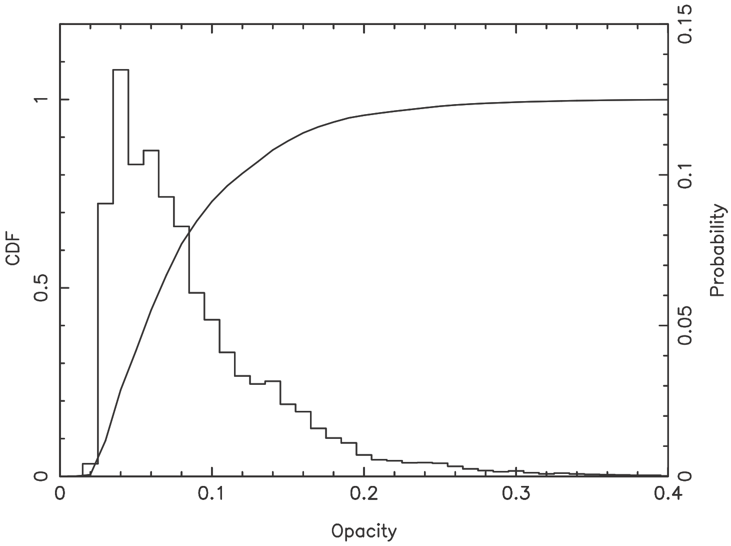

Figure 1. Histogram (right axis) and Cumulative Distribution Function (left axis) of the opacity monitored at the summit of the ice cap on Greenland. We set a tipping radiometer at 225 GHz in August 2011 at the roof of a polar research facility to monitor the opacity. The plotted data are from 17 Aug. 2011 to 13 May 2012, and the quartiles are 0.05, 0.08 and 0.11 for 25, 50 and 75%, respectively.

The antenna has been retrofitted for the cold environment on Greenland, and it is planned to be set up at the summit in 2015. During summer, an air cargo is transporting materials once every week, and every three months in winter.

The overall profile of this GLT project will be presented by K. Asada in this meeting, and here we will give the GLT project a little more in detail.

P101

The 0.9 and 1.3 THz Superconducting HEB Mixer Receiver for the ASTE 10 m Telescope

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In the THz region, there exist many spectral lines of various fundamental atoms, ions and molecules, which give us novel information on chemical and physical state of interstellar clouds including star and planet forming regions. Although observations of these lines have successfully been done with Herschel HIFI, further observations with higher angular resolution from the ground-based telescope are still important for some THz atmospheric windows. With this in mind, we have been developing superconducting HEB (Hot Electron Bolometer) mixers for the THz frequency region at The University of Tokyo. By use of these mixers, we have prepared a cartridge-type THz heterodyne receiver for the 0.9 THz and 1.3-1.5 THz bands, and have successfully conducted a commissioning run in 2011 on the ASTE 10 m telescope (Atacama Chile).

The receiver is the ALMA cartridge type with a single beam. It can observe the dual bands (0.9 THz and 1.3-1.5 THz) simultaneously in the DSB mode by using the wire grid. The IF band is 1.0-1.2 GHz. As for local oscillators (LOs), we use 3 different multiplier chains driven by a microwave synthesizer for the 3 observation frequencies; 0.9, 1.3, 1.5 THz. In the commissioning run, the LOs for 0.9 and 1.3 THz have been installed. We employ the in-house waveguide HEB mixers for the both bands. Although SIS mixers now show a better performance than HEB mixers at 0.9 THz, we use the HEB mixer to demonstrate observation capability of our HEB mixer. We use NbTiN superconducting films fabricated on a quartz substrate for the HEB mixers. The thickness of superconducting microbridges is 10.8 nm. The receiver performance is measured in the test cryostat, and the minimum receiver noise temperatures achieved are as low as 390 K for the 0.8 THz, 490 K for the 1.5 THz mixers.

The lowest system noise temperature including atmospheric attenuation is around 1000 K at 880 GHz, when the precipitable water vapor is 0.18 mm. From the continuum observation of Jupiter, the beam efficiency is derived to be about 30% at 880 GHz for the illumination of the inner 7 m area of the 10 m telescope. Furthermore, we have succeeded in detecting the spectral line of ^{13}CO ($J = 8 - 7$; 881.3 GHz) toward the Orion A molecular cloud. In addition to this, we will report the results of the 2nd commissioning run in 2012.

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Development of Wideband Feed and Receiver System for Kashima 34m Antenna

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Wide band feed and reciver system for Kashima 34m antenna has been developing in NICT. This system uses 4ch, in 3.2-13.8GHz, which are 3.2-4.2GHz, 4.8-5.8GHz, 9.6-10.6GHz, and 12.8-13.8GHz, because of RFI and minimum redundancy in frequency space. It is aimed for precious time transfer by geodetic VLBI technique and for VLBI 2010, also will be a good milestone in a way to future wideband radio telescope system such as SKA. The Author, at first planed the feed by a kind of arrayed TWA(Traveling Wave Antenna)[1], however, we must have developed the feed in 2012 for the operation of time transfer. Thus. the Author decided using a multimode horn within a corrugated horn for the project. This is complicated but easier way than controlling beam width of arrayed TWA. Figure 1 shows the image of the feed and figure 2 shows reciever system block diagram. Conventional down-converter system will be used in the first step, however, it will be evolved into direct sampling system.

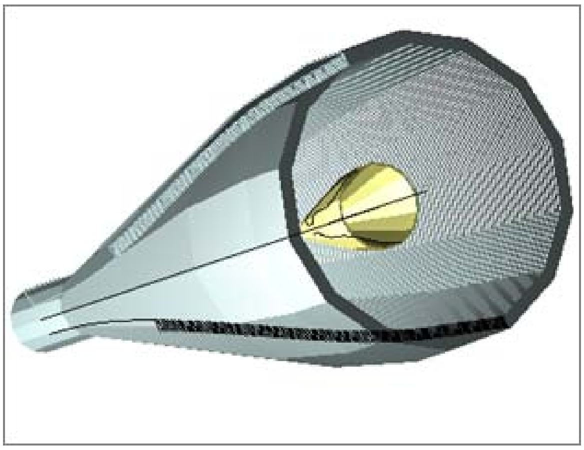

Figure 1: 3D CAD model of feed

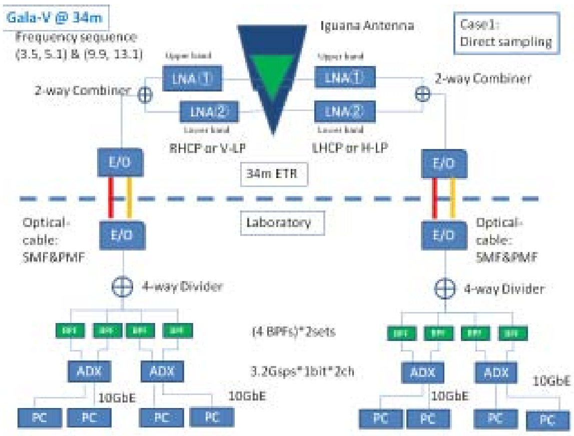

Figure 2: receiver system for 34m antenna.

This system was named ”Gala-V” which means ”Galapagos VLBI”. The feed horns are called Iguana-Mam and Daugter feed. Ofcourse it was named after ”GALA-KEE” which is a domestic cellar phone systems in JAPAN, like the evolution in Galapagos island. The authors selected best frequencies for operation in Kashima, however, the system will be adopted and evolved to fit another location in the world. Becasue our site is seemed to be one of the world highest RFI site.

[1] ”Delopement of mutimode horns and wideband feed for radio telescopes”
H. UJIHARA, K. KIMURA, K. MATSUMOTO, H. OGAWA, T. OHNO, M. TSUBOI, T.KASUGA, M. HOMMA and N. KAWAGUCHI,
General Assembly and Scientific Symposium, 2011 XXXth URSI $(13 - 20 Aug. 2011)$

P103

The 1.85m mm-submm telescope: A newly-developed CO multi-line surveyor

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We have developed the 1.85m mm-submm telescope to improve our understandings of the physical conditions (e.g., temperature, density) of molecular clouds in the Galaxy for bridging the gap in understanding between molecular clouds evolution and star formation therein. The telescope is installed at Nobeyama (Fig.1). We installed a receiver system equipped with 2-SB mixers, which enable us to achieve simultaneous observations of the molecular rotational lines of J=2–1 of carbon monoxide and of the isotopes (^{12}CO, ^{13}CO, and C^{18}O) at 230GHz band. The 2'.7 beam size of the telescope is suitable to obtain a large scale distribution of molecular gas which also can be compared with large-scale observation data in various wavelengths e.g., with Planck, Herschel, Spitzer, Fermi, and so on. In addition, the large scale molecular dataset toward the Galaxy is of intrinsic importance for comparing with giant molecular clouds (GMCs) properties of the external galaxies; we just start resolving spatially the GMCs in the external galaxies with large aperture telescopes in the ALMA era.

We started the project in 2006, and the telescope was move to Nobeyama at the end of 2007. After various commissioning activities, we have successfully started the science observations since January 2011. Our first observing targets include famous star forming molecular clouds covering a variety of star formation environments (Table1). The observation coverage is a few hundred square degrees in total in the first 2 years. From these observations, we found that the observations in ^{13}CO(J=2–1) is quite important to derive precise physical properties. Because of the high critical density for the excitation, the intensity is very sensitive to the density for molecular clouds with a density of $\sim 10^3$cm^{-3} although the ^{13}CO(J=1–0) can trace gas with much lower densities. Furthermore because the ^{13}CO lines tend to be optically thin toward most of the clouds, the line ratios (2–1/1–0) are also very sensitive to the temperature of around 10K. For instance, the distribution of ^{13}CO(J=2–1)/^{13}CO(J=1–0) ratios in the Orion data has a steep gradient around the HII region, ranging from 0 up to $\sim$2 (Fig.2). This change reflects the large fluctuations of the densities and temperatures around the HII region. The ^{13}CO(J=2–1)/^{12}CO(J=2–1) ratio is considered to reflect the local density of around 10^3cm^{-3} due to the high critical density and to the effect of the photon trapping of the ^{12}CO(J=2–1) line. From these reasons, we conclude that the combination of line ratios of ^{13}CO(J=2–1)/^{13}CO(J=1–0) and ^{13}CO(J=2–1)/^{12}CO(J=2–1) is a very powerful tool for the determination of physical properties of molecular clouds (Nishimura et al. 2012 in preparation). The natural extension of this fact is that the combination of two optically thin lines with different transitions and one optically thick line (e.g., ^{13}CO(J=1–0), ^{13}CO(J=3–2), and ^{12}CO(J=3–2)) can be used for the precise derivation of the physical properties of star forming molecular clouds.

Table 1: Observation summary

Name	Map size	Note
Orion	55 deg^2	Massive star formation
CygnusX	43 deg^2	Massive star formation
CygnusOB7	96 deg^2	No star formation
Taurus	42 deg^2	Low mass star formation
Galactic Plane	18 deg^2	

Fig 1: A photo of the telescope.

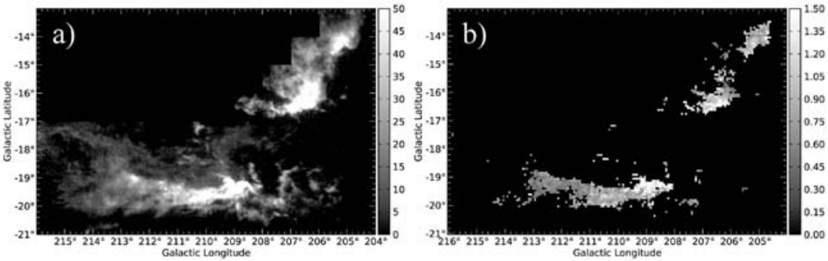

Fig 2: a) Integrated intensity map of the ^{12}CO(J=2–1) emission in the Orion molecular cloud observed by the 1.85m telescope. b) Line ratio map of ^{13}CO(J=2–1)/^{13}CO(J=1–0). J=1–0 data were observed in Nagahama et al. 1998.

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Photon Counting Terahertz Interferometry for Exo-Planet Imagings

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Terehertz frequency region is a frontier of radio astronomy, which is overlapped with far-infrared wavelength. In this frequency region, radio technology and photon technology both can work. In this presentation, I will discuss on a new interferometer technology that uses the combined technology of photons and waves.

We are proposing Photon Counting Terahertz Interferometry (PCTI) for future instrumentation, which is based on an intensity interferometry demonstrated by Hanbury-Brown and Twiss (1956), but using photon counting detectors in terahertz frequencies. Photons follow Bose-Einstein statistics, so coherent behavior of photons such as photon bunching is observed, which is a source of noise for direct detectors. But, this photon bunching is important for intensity interferometry to be effective. In optical wavelengths, photon bunching is less and photon bunching is observed when the source brightness temperature is more than 10^5 K.

In terahertz frequencies, the brightness temperature of 100 K is enough to observe the photon bunching, because the photon energy is much lower. Also, if we count all the photon arrivals, we can, in principle, identify arrivals of photon bunches, such as mean arrival times of bunched photons. When corresponding photon bunches are identified from two separate telescopes, the time tagging of photon bunches can be used to measure the delay of photon arrivals, hence, phase information can be obtained.

The practical photon arrival time for astronomical observation is estimated to be 1-100 MHz. This can be met by fast photon counting detectors in infrared wavelength, but not yet feasible in terahertz frequencies. There are a number of detector technologies which can bed applied to realize this, such as superconducting tunnel junction detectors, superconducting single photon detectors and semiconductor detectors.

Observing target in terahertz frequency region is compact sources with brightness temperature higher than about 100 K. One example is far-infrared atomic fine-structure lines, such as [CII], [NII], [OIII], from starforming regions. Another example is exo-planet searches, which requires very high angular resolutions. The highest angular resolution by PCTI can be achieved by VLBI like system. High timing accuracy for VLBI can be used together with the photon counting detectors to measure delay of photon bunches. When baseline larger than 1000 km is realized at 2 THz, you can start to resolve exo-planets, earth-like planets around nearby stars.

Although this is a case study of a future interferometer technology, fast and high dynamic range detectors for interferometry will open new frontier of terahertz astronomy and astrophysics.

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