Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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HINOTORI and Maser Observations

Keisuke Nakashima[1], **Ka-Yiu Shum**[1], **Hiroshi Imai**[2,3] **and HINOTORI Collaboration**

[1]Faculty of Science, Kagoshima University, 1-21-35 Korimoto, Kagoshima 890-0065, Japan, email: k8024878@kadai.jp

[2]Amanogawa Galaxy Astronomy Research Center, Graduate School of Science and Engineering,

Kagoshima University, 1-21-35 Korimoto, Kagoshima 890-0065, Japan,

[3]Center for General Education, Institute for Comprehensive Education, Kagoshima University,

1-21-30 Korimoto, Kagoshima 890-0065, Japan

Abstract. HINOTORI (Hybrid Integration Project in Nobeyama, Triple-band Oriented) has constructed a higher sensitivity 22/43 GHz and a 22/43/86 GHz simultaneous observation systems in the Nobeyama 45-m telescope by introducing new frequency separation filters in the telescope's quasi-optics. The performance of the observation systems, such as the beam squint, the aperture efficiency, the system noise temperature when inserting the filters, and the phase stability of the signal path have been evaluated. It is indicated that the established systems have sufficient performance for single-dish and VLBI observations. The single-dish observation demonstrations using the triple-band system were successfully conducted in acquiring scientific data including multiple maser lines.

Keywords. masers, instrumentation: interferometers

1. Introduction

HINOTORI is a project to realize simultaneous single-dish and VLBI observations in three frequency (22, 43, and 86 GHz) bands with the Nobeyama 45 m telescope (Okada *et al.* 2020). Four receivers named H22 (22 GHz, RHCP+LHCP), H40 (43 GHz, LHCP), Z45 (43 GHz, two orthogonal linear polarizations), and TZ (86 GHz, two orthogonal linear polarizations) are used in this project for radio signals flow from the quasi-optics of this telescope (Imai *et al.* 2022). The H22+H40 simultaneous observation system has already been established and used for scientific single-dish and VLBI observations. This time, we have established new simultaneous observing systems, H22+Z45 and H22+H40+TZ, by installing another frequency-separating filters. Here, we summarize the instrumental performance of these simultaneous observation systems and the observation demonstrations in the H22+H40+TZ mode.

2. System evaluation

The beam squint measurements with the new filters have been conducted using the data of H_2O, SiO $v=1$ and 2 ($J=1\rightarrow 0$) maser lines for the H22+Z45 mode and SiO $v=1$ ($J=2\rightarrow 1$ and $1\rightarrow 0$) maser lines for the H22+H40+TZ mode. The pointing offsets of H22 and Z45 with the filters due to the bean squint were distributed around $(dAz, dEl)\sim(+3'', +7'')$, respectively (Imai *et al.* 2022). The pointing offsets of TZ in the H22+H40+TZ mode was distributed around $(dAz, dEl)\sim(+3'', +3'')$. These distributions are smaller than 1/6 of each beam size, resulting in a negligible effect on

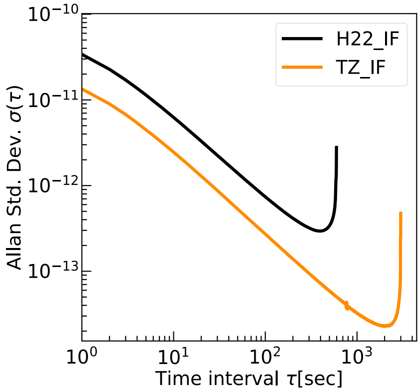

Figure 1. Phase stability of IF signals at 6 GHz from TZ and 5.435 GHz from H22 (used in VLBI). The IF signals from TZ have a phase variation less than 0.1 rad per second. The phase stability is comparable to that of H22, which is currently used for simultaneous 22/43 GHz VLBI observations, and stable for longer than the timescale of the atmospheric variability, so that the effect of phase fluctuations due to the observing system is less than thermal fluctuations, at least on that timescale.

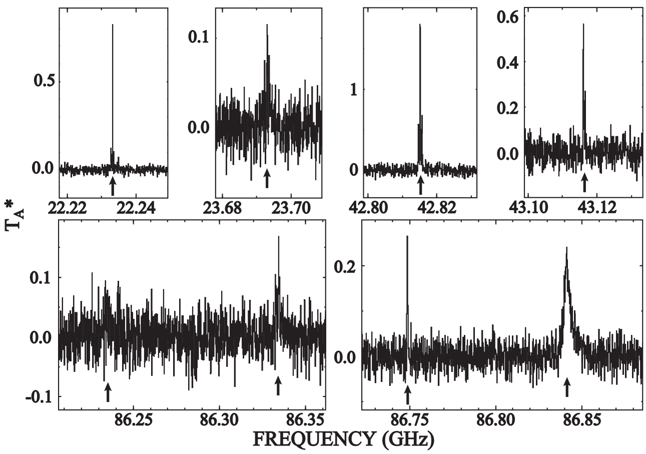

Figure 2. Spectra of IRAS 19312+1950 obtained from single-dish observations on January 17, 2023, using the H22+H40+TZ simultaneous observation system. Molecules detected and indicated by arrows are (from top left to bottom right sub-panel): H_2O, NH_3, SiO $v=2$ and 1 (J=1→0), SiO $v=1$ (J=2→1), $H^{13}CN$ (J=1→0), $H^{13}CO^+$ (J=1→0) and SiO $v=0$ (J=2→1) and also identified by Qiu *et al.* (2023).

observations of point-like sources such as maser sources. The beam sizes with the new filters are unchanged ($\sim 75''$, $\sim 41''$ and $\sim 19''$ for H22, Z45 and TZ, respectively). The aperture efficiency was $\eta_A \sim 52\%$ for Z45 with the new filter, 5 points lower than that of H40 without the filter ($\eta_A \sim 57\%$) for the former two-band mode, and $\eta_A \sim 32\%$ for TZ with filters, 11 points lower than that of TZ without the filters ($\eta_A \sim 43\%$). The decrease in η_A in the former case is consistent with that in the H22+H40 simultaneous observation system already in use for scientific observations today within 1%. The system noise temperature was $T_{\rm sys}$ ~140 K for Z45 with the filter, 20 K lower than that of H40 without the filter ($T_{\rm sys}$ ~120 K) for the former mode, and $T_{\rm sys}$ ~500 K for TZ with filters, 100 K lower than that of TZ without filters ($T_{\rm sys}$ ~400 K) for the latter triple-band mode.

The phase stability of the intermediate frequency (IF) signal path from TZ has also been measured because we have installed a new remotely controllable signal generator

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as the first local oscillator of TZ. It was evaluated with Allan standard deviations $\sigma(\tau)$, which were measured by observing artificial RF signals, converting them to IF signals with the new signal generator, and comparing the converted signals with those directly from another high-quality signal generator. The measured stability looked sufficient for VLBI observations (Figure 1).

3. Observation demonstrations of the H22+H40+TZ mode

Single-dish observation demonstrations in the H22+H40+TZ simultaneous observation mode toward IRAS 19312+1950 have confirmed that a variety of maser lines can be simultaneously detected (Figure 2). Thus, one can see multiple maser sources within a common antenna beam, which should be the targets of future simultaneous single-dish and VLBI observations for study on high-mass star formation and the progress and fades of copious mass loss from dying stars.

References

Imai, H., Ogawa, H., Niimura, K., *et al.* 2022, Proceedings of the 2022 Asian-Pacific Microwave Conference (APMC), 587

Okada, N., Matsumoto, T., Kondo, H., *et al.* 2020, Proceedings of SPIE 11453, 1145349

Qiu, J.-J., Zhang, Y., Nakashima, J.-i., *et al.* 2023, *A&A*, 669, A121

https://doi.org/10.1017/S1743921323002740 Published online by Cambridge University Press