KaVA Large Projects on Circumstellar Masers as Synergy with ALMA

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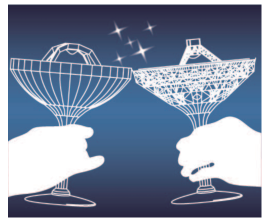


Time line and scientific views of the KaVA (KVN and VERA Combinded VLBI Array) Large Programs on circumstellar masers

Phase 1: ESTEMA

(Exapnded Study on Stellar Masers) ongoing
during 2015 autumn—2016, 2 years ×120 hours
Snapshot imaging of H_2O and SiO masers in circumstellar envelopes (Figure 1)
around ~80 stars (source list in public)

- statistics of stellar masers
  - i. maser spot sizes and shapes
  - ii. distributions of H_2O masers with respect to locations of SiO masers
  - iii. correlation with kinematic parameters of circumstellar envelopes and stars
- yielding a larger sample of stars as targets of the Phase 2 project

Phase 2: Intensive monitoring campaign

during 2016—2024, 400—500 hours/year
16—20 pulsating stars (P=300—1600 days)
monitoring SiO and H_2O masers in every 1/20 pulsation cycle over a few pulsation cycles for "stellar maser movie" synthesis

- detecting (both or either)
  - i) propagation of pulsation-driven shock waves (Figure 2)
  - ii) periodic change in physical conditions affected by stellar radiation
- Comprehensive synergy with ALMA, VLTI, Nano-JASMINE for tracing transition from gas to dust

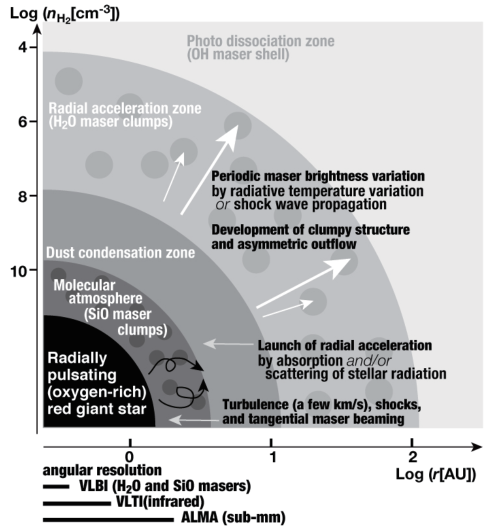


Figure 1
Schematic view of the spatial and density structure of a circumstellar envelope of an oxygen-rich (intermediate-mass) long-period pulsating star that hosts SiO and H_2O masers. Gas ejected from the stellar surface forms molecules, then oxygen/silicon-rich dust (e.g. silicate and olivine). The dust particles are accelerated by stellar radiative pressure received through scattering of stellar infrared radiation. The microscopic (dust condensation) and macroscopic (turbulence, shock waves) process should be linked and explored in the KaVA projects.

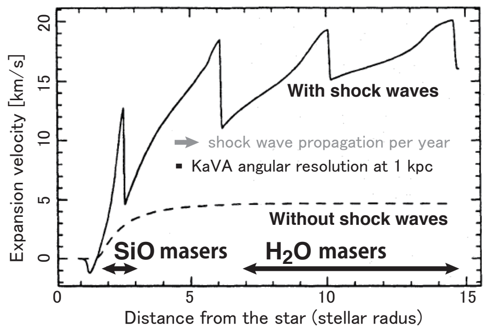
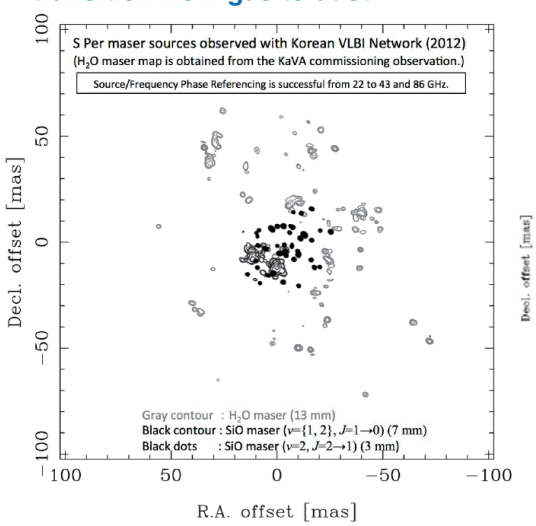


Figure 2
Schematic view of the radial velocity field of a circumstellar envelope of a pulsating star and the locations of the hosting SiO and H_2O masers. Pulsation-driven shock waves will be detectable by directly finding the velocity field and its time variation in the intensive KaVA monitoring programs over a few stellar pulsation cycles.



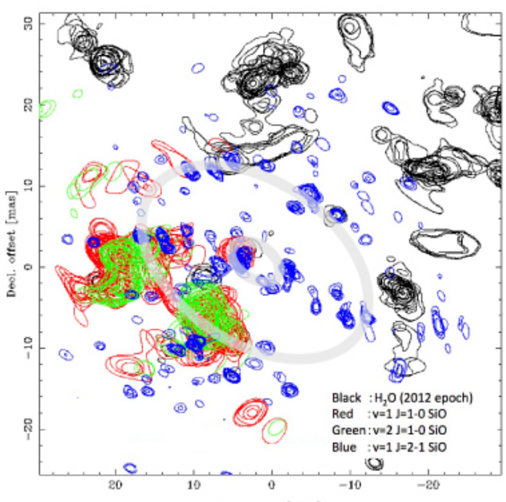


Figure 3 (left)
Composite map of the H_2O and SiO masers towards a red supergiant S Persi obtained by a KaVA/KVN demonstration of band-to-band calibration among 22/43/86 GHz bands (Asaki et al. in preparation). The observation was made on 2012 Mar. 30, when VERA and KVN observed, respectively,H_2O(22 GHz) and H_2O/SiO (43&86 GHz) masers, at the same time.

Figure 4 (right)
Zoom-up view of the inner part of the composite map shown in Figure 3. The relative positions of the masers shed light on the major maser pumping mechanism (here line overlap between MIR transitions of H_2O/SiO is preferable).

Operation design for the KaVA Large Programs

Multiple missions in each KaVA observation session

Two-day pairs of blocks for 22/43GHz bands with VERA for 22/43/86/129 GHz bands with KVN in each observation session for

1. high quality imaging of H_2O and 43 GHz (v=1 & 2 J=1→0) SiO masers,
2. mapping of 86 and 129 GHz SiO (v=1 & J=2→1 and J=3→2) masers with the KVN through band-to-band calibration,
3. high precision of astrometry of masers with VERA dual-beam system.

See the frequency band allocation (Figure 5)

Decadal monitoring program of stellar masers in the Phase 2 project

~500 hours, ~20 sessions, ~12 stars per year (~20 stars in total)
~3 stars (~9 stars in total) with P~300 d /yr observed in every 2 weeks
~3 stars (~6 stars in total) with P~600 d /yr observed in every 4 weeks
~6 stars with P~1200 d /yr observe in every 8 weeks

Open questions as scientific drivers in planning synergy with ALMA

How to find where and when dust is formed from specific molecules?
How to evalutate the efficiency of dust acceleration and its variation?
What do the masers trace
(suppiers of material of dust, dust condence region)?

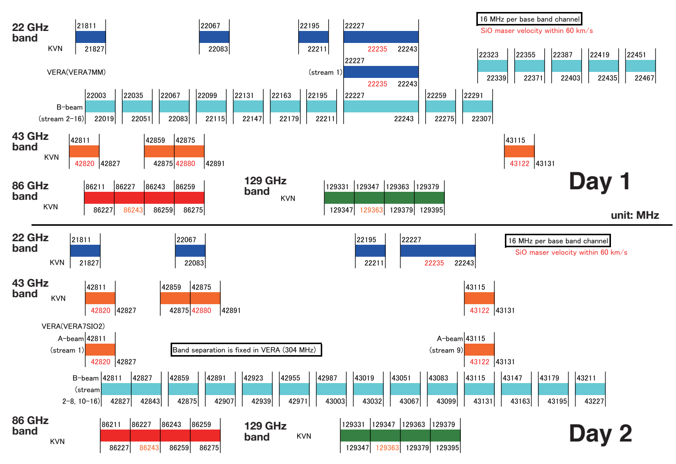


Figure 5 Frequency band allocations for the KaVA ESTEMA.