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RadioAstron study of galactic and extragalactic water masers

First space-ground detection of extragalactic megamaser: NGC 4258

RadioAstron has detected water maser emission from the circumnuclear disk of NGC 4258 galaxy. NGC 4258 (also known as Messier 106) is a spiral galaxy (Seyfert II type) located at the distance of 7.6 Mpc in the constellation Canes Venatici. The H_2O Megamaser NGC 4258 is a prototype object with maser spots tracing the accretion disk around a supermassive black hole. The pumping is provided by the influence of X-ray emission from the center of the galaxy on the disk material. The existence of multiple components is explained by turbulence and instabilities in the disk. Interferometric signals were obtained with the space radio telescope (SRT) Spektr-R of the RadioAstron project and two ground facilities, the 100-m radio telescope in Green-Bank (USA) and the 32-m radio telescope in Torun (Poland) on 18 December 2014 (Figure 1). The spectrum in the figure shows a 30 minute integration. The extremely small spread among the fringe phases with velocity shows how remarkably thin the actual distribution of masers in the accretion disk is.

The projected baseline length was up to 2 Earth diameters, corresponding to a fringe spacing of about 110 μas. This first extragalactic detection suggests that H_2O Megamasers can be successfully studied with RadioAstron and that high resolution SVLBI imaging of H_2O Megamasers is possible leading to a detailed analysis of circumnuclear disks in other galaxies.

Water masers in star-forming regions of our Galaxy: Orion KL, W49 N, W3 (H_2O)

Successful detection of interferometric fringes from very compact water maser feature associated with the nearest and well studied high-mass star-forming region Orion KL within the RadioAstron key science maser program is reported. Orion KL is a part of the Orion Nebular Cloud Complex and is located around 420 pc from the Sun. Active star formation occurs in this source, accompanied by a powerful maser radiation. Results of previous studies suggest that the compact maser spots are associated with the highly collimated outflow from the accreting young stellar object. The brightness temperature of the detected compact maser spot can exceed 10^{15} K. Correlated signals were obtained between the space and ground telescopes in two sessions. The 40-m radio telescope in Yebes (Spain), and the 32-m radio telescope in Torun (Poland) took part in the first session on 29 November 2013. The projected baseline length reached 3.5 Earth diameters, corresponding to a fringe spacing of $\sim$63 μas. This corresponds to a linear size of about 3 solar diameters. In the second session (25 December 2013) Orion KL was detected on a baseline to the 26-m radio telescope in Hartebeesthoek (South Africa) with projected baseline of 2 Earth diameters. In both sessions V_{LSR} and line width of the detected maser detail were around 7.3 km/s and $\sim$0.5 km/s, respectively.

Observations of the most luminous water maser source in the Galaxy, star-forming region W49 N, also resulted in a successful fringe detection. W49 N is located at a distance of about 11 Kpc from the Sun in a distant part of the Perseus arm near the solar circle. A correlated signal was obtained on 2014 April, 18 between the space antenna and the 100-m ground radio telescope in Effelsberg (Germany). Projected baselines of the space-ground interferometer in the experiment reached up to about 3 Earth diameters (38,000 km), achieving a fringe-spacing resolution of $\sim$70 μas.

A re-analysis of early RadioAstron observations at the ASC correlator has delivered a positive result for W3 (H_2O), the bright water maser complex located $\sim$ 6 arcseconds to the east of the W3 (OH) ultracompact H II region. A correlated signal was detected between the space antenna and the 100-m ground radio telescope in Effelsberg (Germany) and 40-m radio telescope in Yebes (Spain). Projected baselines of the space-ground interferometer in the experiment reached up to 3.8 Earth diameters (about 48,000 km), achieving a fringe-spacing resolution of $\sim$ 58 μas.

The collected data on water masers are used to study structure and physical characteristics of the star forming regions in our Galaxy, impose tight limits on the sizes of individual maser spots, estimate brightness temperatures and provide the necessary input for the studies of their pumping mechanisms.

First imaging of water masers with RadioAstron

A RadioAstron imaging of a water maser in the star-forming region W3 IRS5 took place on 17 October 2013 with participation of the European VLBI Network (EVN) including the Russian network "Quasar". Interferometric signals have been detected up to 6 Earth diameters delivering a record angular resolution of 36 μas for water masers. This corresponds to linear resolution of $\sim 10^7$ km. The space-ground interferometric image of the bright maser component in W3 IRS5 is shown in the left panel of Figure 2. The ground-only image has an extended structure, resolved out with the space-ground RadioAstron baselines except for a very compact peak visible up to the 6 Earth diameters. A joint analysis of the RadioAstron data and results of Japanese VERA interferometer monitoring allows international team of scientists to identify locations of the most compact maser emission (right panel, Figure 2).

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The RadioAstron project is led by the Astro Space Center of the Lebedev Physical Institute of the Russian Academy of Sciences and the Lavochkin Scientific and Production Association under a contract with the Russian Federal Space Agency, in collaboration with partner organizations in Russia and other countries.

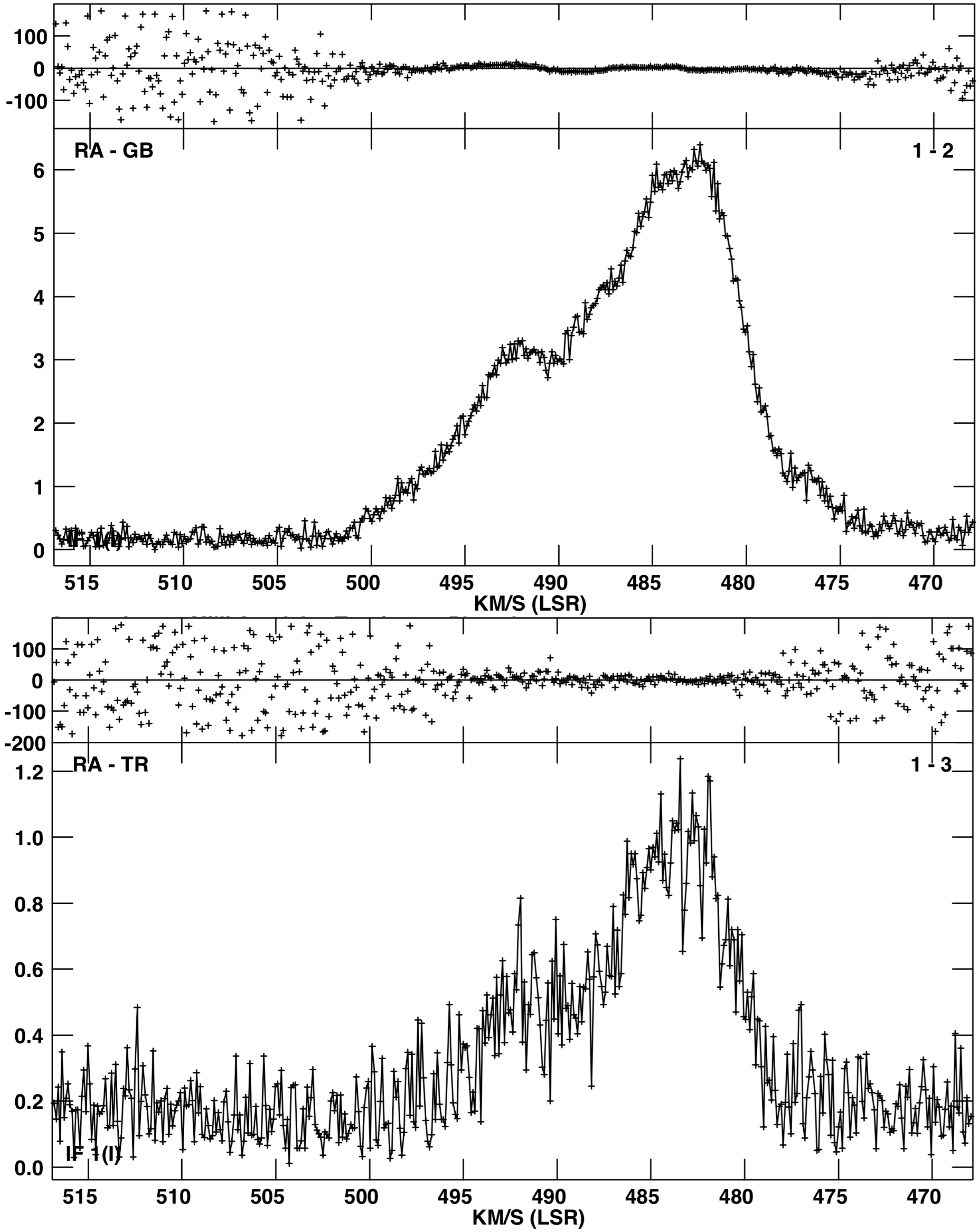

Figure 1: Cross-correlation spectra of Megamaser emission in the galaxy NGC 4258 obtained on space-ground baselines to the 100-m radio telescope in Green Bank (top) and 32-m radio telescope in Torun (bottom). The plots shows amplitude in arbitrary units and phase in degrees versus velocity in km/s recalculated to the LSR rest frame. The phase slope has been removed for this presentation. Fringe detections with high SNR occur in velocity ranges with small scatter in phase.

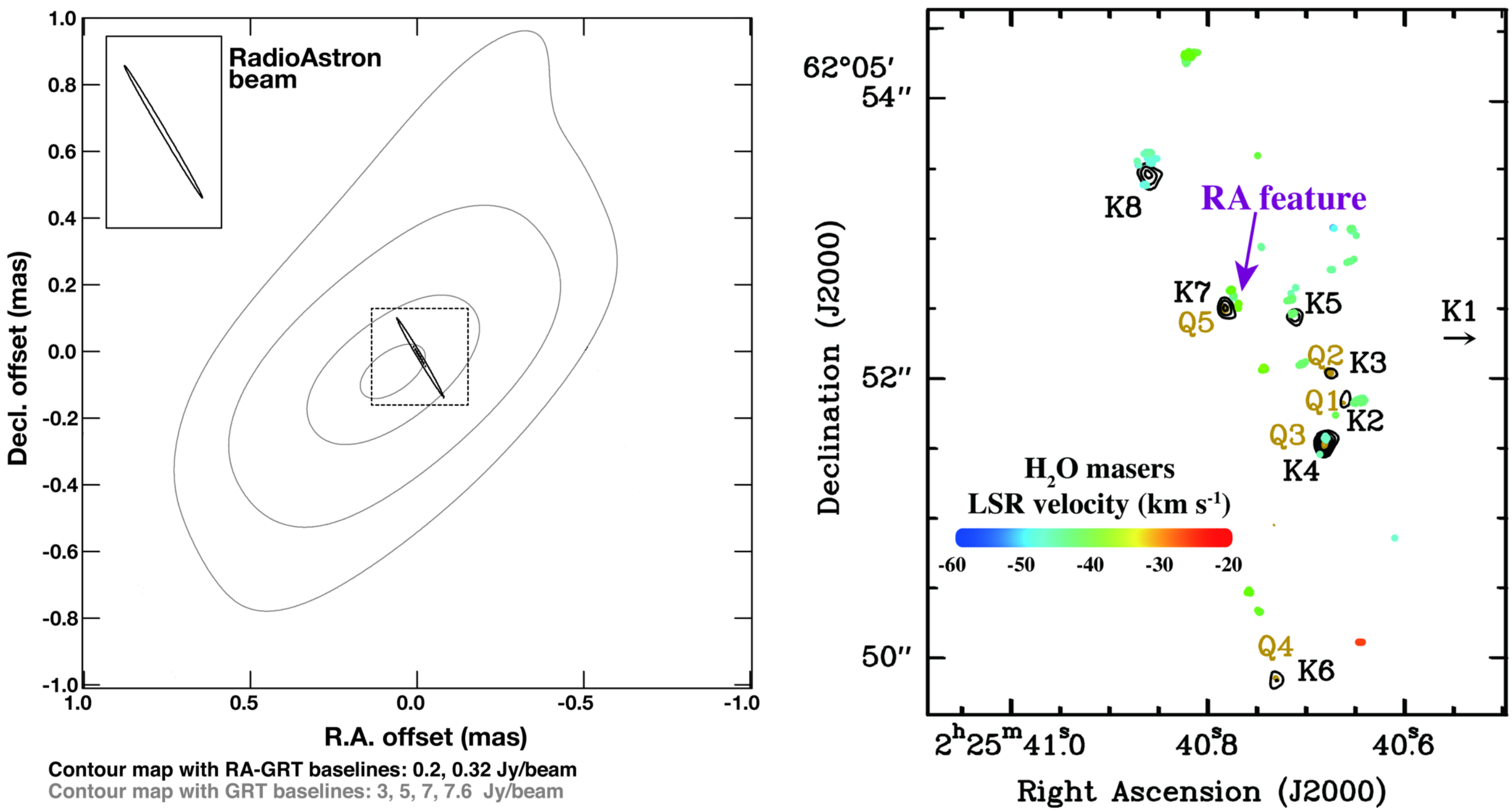

Figure 2: W3 IRS5 left: contour map of the brightest H_2O spot detected in RadioAstron-EVN session on 17 October 2013. The image created in the narrow velocity range (0.1 km/s) corresponds to the peak spectral channel. The grey and black contours indicate the maser brightness distribution from RadioAstorn and ground-only data, respectively. The synthesized RadioAstron-EVN beam is displayed at the top-left corner of the map. Note that side lobes at the level up to 60 % of the real central brightest peak are omitted to avoid confusion. Right panel shows distribution of H_2O maser spots from W3 IRS5 as seen by the Japanese VERA interferometer 48 days before the RadioAstorn observation. The brightest compact maser feature is the one detected by RadioAstorn (magenta arrow). Brown and black contours indicated the brightness distributions of the 7-mm and 13-mm band continuum emission, respectively (van der Tak et al. 2005).