# Bursting $H_2O$ maser source G25.65+1.05: from single-dish to space VLBI

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&

Masers Monitoring Organization
https://m2o.hartrao.ac.za/

**25.65+1.05:**

| Alias | Coordinates | System Velocity* | Kinematic Distance** | Detected Maser Species | |
|---|---|---|---|---|---|
| RAFGL7009S<br>IRAS 18316-0602 | RA (J2000) = 18h34m21s<br>DEC (J2000) = -05°59'42" | 42.5 km/s | 2.08 kpc (near)<br>12.5 kpc (far) | 1665/1667 MHz OH<br>6.7 GHz CH3OH (class II) | 22 GHz H2O<br>44 GHz CH3OH (class I) |

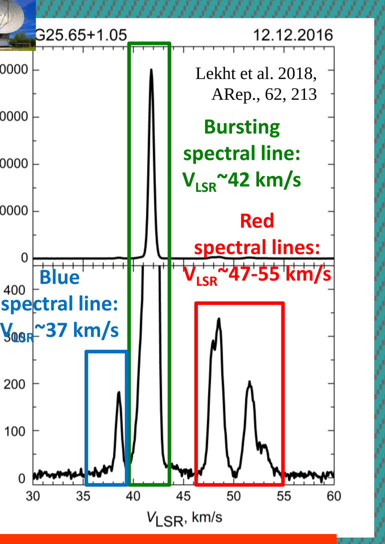
* Derived from the hyperfine fit to the $N_2H^+$ (1–0) and $C_2H$ (1–0) lines [Sánchez-Monge et al. 2013].
** The distance to the source is a debatable question - VLBI measurements of the trigonometric parallax have never been performed for the source. In our calculations below we will use the value of 2.08 kpc calculated on the basis of The Bar and Spiral Structure Legacy (BeSSeL, http://bessel.vlbi-astrometry.org) Survey data (Reid et al. 2016).

**G25.65+1.05 is a new one of only three** Galactic water maser together with **W49N** and **Orion KL** that are known **to flare** to the level of **$10^5$-$10^6$ Jy ($T_B$ ~ $10^{17}$ K)**

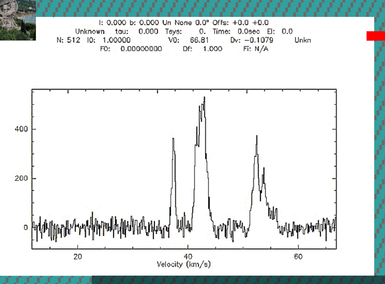
**BUT**

In contrast to them, the source is **less known** and did not attract as much attention before – there are only single-dish data on $H_2O$ maser emission (see review at the bottom)

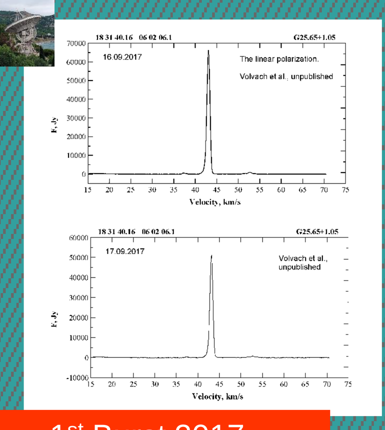
**In 2017-2018 three $H_2O$ maser bursts with flux densities of 60-70 kJy *(see $H_2O$ Maser Spectra Timeline at the left)* were detected in G25.65+1.05 – it triggered intensive study of the source with a wide range of baselines. We present the results - observations are arranged by resolution in decreasing order.**



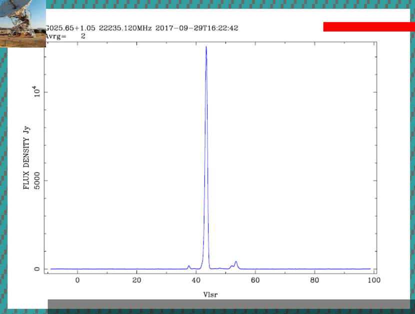

Burst 2016
2016 December 12
RT-22 Pushchino



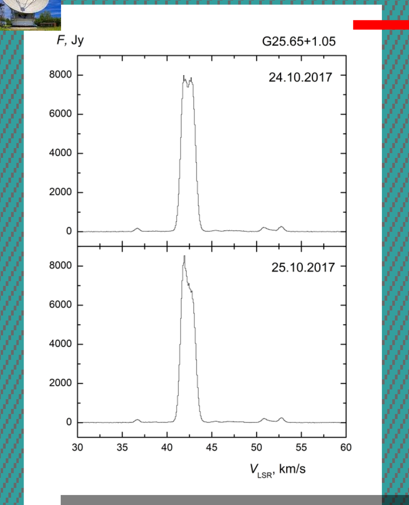
2017 August 10
RT-22 Simeiz



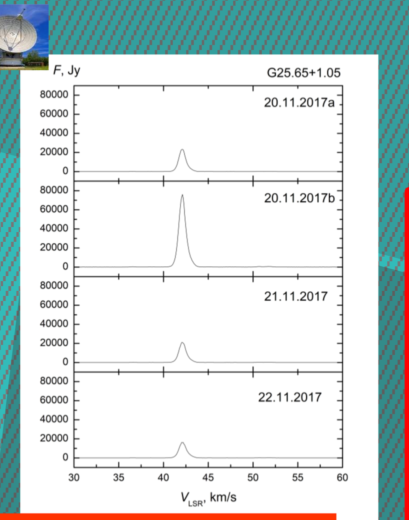
1st Burst 2017
2017 June 16
RT-22 Simeiz



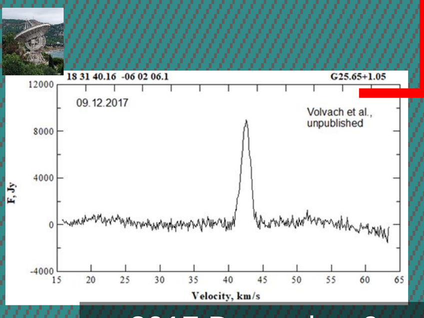
2017 September 29
RT-26 HartRAO
(private report)



2017 October 24-25
RT-22 Pushchino



2nd Burst 2017
2017 November 20
RT-22 Pushchino



2017 December 9
RT-22 Simeiz)

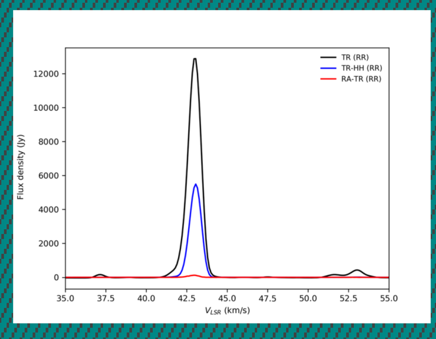
## OBSERVATIONS | RESULTS

### RadioAstron: 10-m SRT + 32-m Torun + 26-m HartRAO
**9 Earth Diameters baseline – the best resolution of 24 μas!**

**JUST BURST EPOCH!**

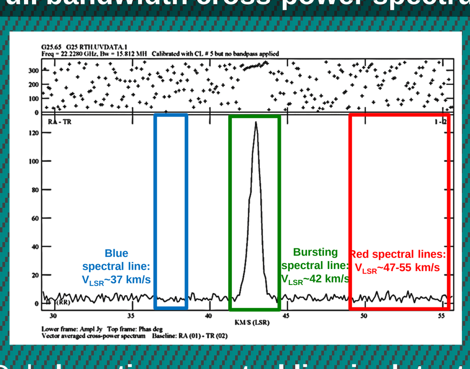
| | | |
|---|---|---|
| Ground array: | • 32-m radio telescope of the Torun Centre for Astronomy of Nicolaus Copernicus University (Tr, Torun, Poland)<br>• 26-m radio telescope of the Hartebeesthoek Radio Astronomy Observatory (Hh, Johannesburg, South Africa) | |
| Epoch: | 2017 Sep 29 (Post-burst/flaring state) | |
| Band: | K (22 GHz) | |
| Baseline: | Ground-ground | Space-ground |
| Observation time: | 4 hours | 50 minutes |
| Baseline length: | ~9 000 km (~0.7 ED) | ~115 000 km (~9 ED) |
| Angular resolution: | ~0.3 mas | ~24 μas |

- ✓ **The closest to the burst observation of the source**
- ✓ **The unique projected baseline length of 9 Earth Diameters and angular resolution of just tens of μas**
- ✓ **Super-compact structure of the bursting feature is revealed**
- ✓ **The result is obtained with antennas of intermediate size!**



Single dish flux density: **~12 000 Jy**
Correlated flux density on RA-ground baseline: **~120 Jy**

**Full bandwidth cross-power spectrum**



Only **bursting spectral line is detected** by RadioAstron in this session!

Estimated **size of the bursting maser features** at the velocities ~42 km/s detected at space-ground baselines is **~23 μas*** with a brightness temperature **Tb ~4 x $10^{16}$ K***

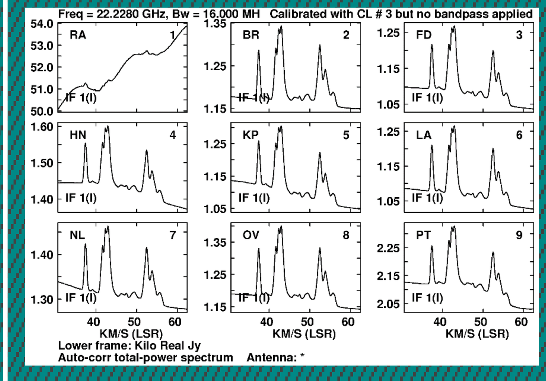
*Calculated according to (Lobanov 2015, A&A, 574, A84):
$\theta_r = \frac{2\sqrt{\ln 2}\,\lambda}{\pi\,B}\sqrt{\ln(V_0/V_q)}$ & $T_{b,min} = \frac{\pi e}{2k}B^2 V_0 \approx 3.09\left(\frac{B}{km}\right)^2\left(\frac{V_q}{mJy}\right)$ [K],
where $\theta_r$ - the size of the emitting region, $T_{b,min}$ - the minimum of the brightness temperature, $V_0$ and $V_q$ - the zero-spacing and visibility flux densities at a spatial frequency q.

### RadioAstron: 10-m SRT + VLBA *(pre-burst epoch)*:
**the best resolution image at 22 GHz of 80 μas**

| | | |
|---|---|---|
| Ground array: | VLBA (8 antennas: HN, NL, FD, LA, PT, KP, OV, BR) | |
| Epoch: | 2017 Aug 10 (Post-burst/stable state) | |
| Band: | K (22 GHz) | |
| Baseline: | Ground-ground | Space-ground |
| Observation time: | 6 hours | 90 minutes |
| Baseline length: | ~4 000 km (~0.3 ED) | ~34 400 km (~2.7 ED) |
| Angular resolution: | ~0.4 mas | ~80 μas |

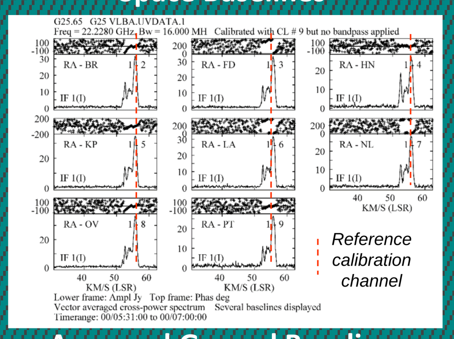
- ✓ **The only stable-state observations of the source at the moment**
- ✓ **The projected baseline length of 2 Earth Diameters and angular resolution of about 1 mas**
- ✓ **The unique resolution mapping of the source**

**Auto-correlation spectra**

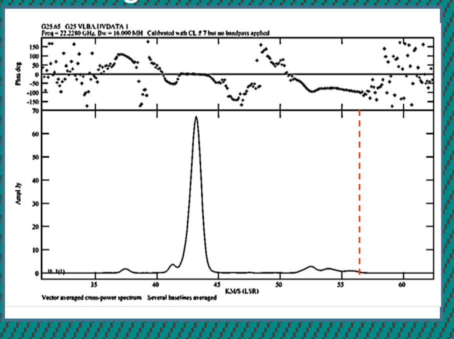


- Single dish flux density: ~200 Jy
- Correlated flux density on RA-ground baseline: ~30 Jy
- Signal is detected on all space-ground baselines

**Cross-power spectra**
**Space Baselines**




**Averaged Ground Baselines**



Only red spectral lines are detected by RadioAstron in this session!

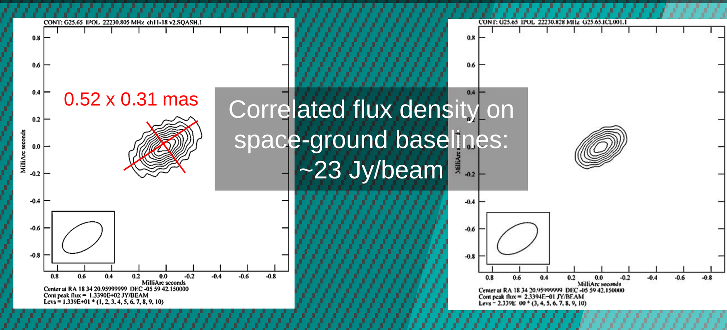
Estimated size of maser features detected on space-ground baselines at the velocity of 51 km/s is **~0.027 mas*** with brightness temperature **Tb ~1.5 x $10^{14}$ K***

**Correlated flux density remains almost constant with increasing baseline length.**

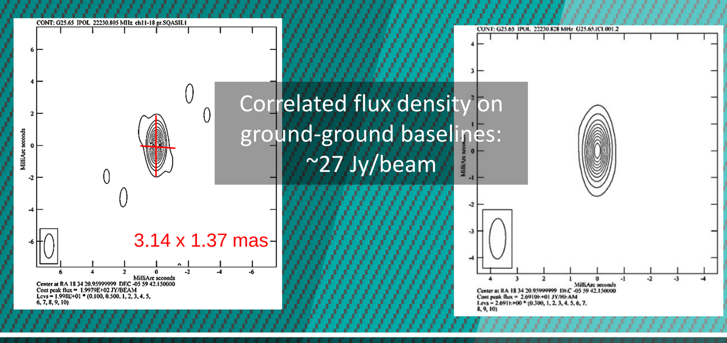
**This indicates that the detected feature is very compact!**

| Images of the velocity-integrated *(7 channels averaged)* red maser group at ~51 km/s | Image of calibration channel #363 ($V_{LSR}$ = 55.7 km/s) |
|---|---|

**Space segment**




**Ground segment**




## GROUND SUPPORT AFTER GIANT BURSTS *(4 experiments)*:

### EVN / VLBA / KaVA (resolution of ~0.5 mas)

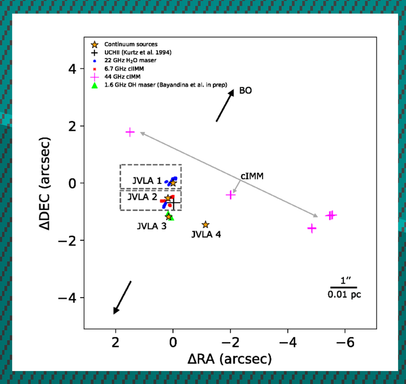
| Ground array: | EVN | KaVA | VLBA |
|---|---|---|---|
| Epoch: | 2017 Oct 2 | 2017 Oct 11 | 2017 Oct 28 |
| Band: | K (22 GHz) | K (22 GHz)<br>Q (44 GHz) | K (22 GHz) |

**For more details see the talk**
**R. A. Burns et al. "Multi-epoch VLBI of a double maser super-burst"**
**(Wednesday, 10th, 13:00 - 13:15, Stellar Evolution Session 3)**

### VLA (resolution of ~0.3")

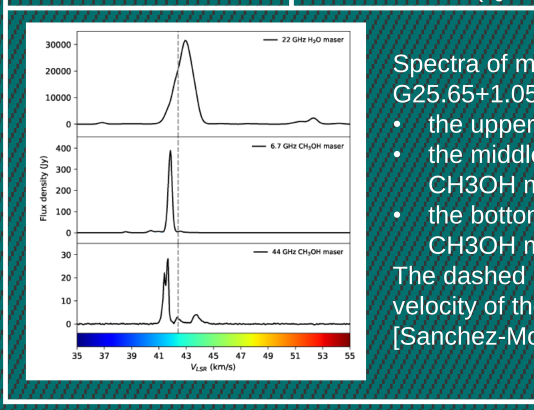
| | |
|---|---|
| Ground array: | B-configuration |
| Epoch: | 2017 Dec 9<br>(Post-burst/flaring state) |
| Band: | C (6.0 GHz), Ku (15 GHz), K (22 GHz), Q (44 GHz)<br>(spectral line + continuum) |
| Observation time: | 2 hours |
| Baseline length: | ~11 km |
| Angular resolution: | ~1 arcsec (C-band)<br>~0.42 arcsec (Ku-band)<br>~0.28 arcsec (K-band)<br>~0.14 arcsec (Q-band) |

- ✓ **The first multi-frequency compact array overview on continuum and maser emission in the source**
- ✓ **For the first time ever four continuum sources are resolved in the field**
- ✓ **The first map of 44 GHz $CH_3OH$ maser emission in the source is obtained**




Objects detected toward G25.65+1.05 with the JVLA:
- continuum sources - orange stars, 22 GHz H2O masers - blue circles, 6.7 GHz cIIMMs - red "x" crosses,
- 44 GHz cIMMs - magenta crosses, 1665 MHz OH masers (pre-burst C-configuration JVLA observations of 2013, [Bayandina et al. (2018)] - green triangles.

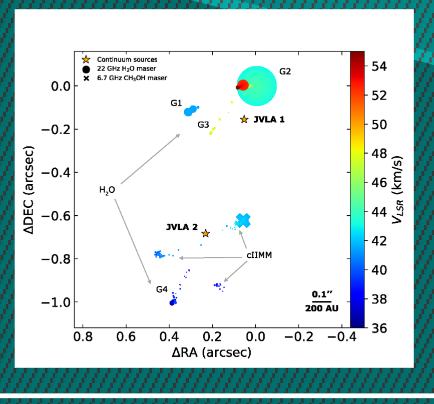
Black cross indicates the position of UCHII region detected at 3.6 cm in Kurtz et al. (1994). Black arrows represent the direction and the position angle (but not the actual position) of bipolar outflow from Sanchez-Monge et al. (2013). Positional offsets are relative to the JVLA 1 continuum source. The physical scale label (in pc) assumes the distance to the source of 2.08 kpc (the BeSSeL Survey Bayesian Distance Calculator).




Spectra of maser species detected toward G25.65+1.05:
- the upper panel - 22 GHz H2O maser,
- the middle panel - 6.7 GHz class II CH3OH maser,
- the bottom panel - 44 GHz class I CH3OH maser.

The dashed line indicates the systemic velocity of the source $V_{LSR}$=+42.41 [Sanchez-Monge et al. 2013].

Bursting maser feature is located in the vicinity of the brightest continuum source in the G25.65+1.05 field and probably associated with the bow shock




Distribution of 22 GHz H2O (marked by circles) and 6.7 GHz CH3OH (marked by \x" crosses) maser spots detected in vicinity of JVLA 1 and 2 sources.

The diameter of each spot is proportional to the flux. Plot is color-coded by radial velocity (see colorbar for color scale). Positional offsets are relative to the strongest 22 GHz H2O maser spot. The physical scale label (in AU) assumes the distance to the source of 2.08 kpc.

9 ED
2 ED
1 ED

## $H_2O$ Maser Spectra Timeline

Long-term monitoring of $H_2O$ maser with the RT-22 of the Pushchino Radio Astronomy Observatory (Moscow region) showed three flares in 2002, 2010, and 2016 with the flux density of 3 400, 19 000, and 46 000 Jy, respectively [Lekht et al. 2018]. The next powerful burst of 65 000 Jy was detected in September 2017 [Volvach et al. 2017a] with RT-22 of the Crimean Astrophysical Observatory. In October 2017 shortly after this burst the source showed new increase of flux density - see [Volvach et al. 2017b]. The most recent registered burst was found to be a short-lived with the peak flux density rose from ~20 to 76 kJy within half a day on November 20, the source faded to ~20 kJy on November 22 [Ashimbaeva et al. 2017].

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