PROCEEDINGS OF SCIENCE

# OH eruptive event in Mira Ceti

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*o* Ceti is known as the prototype of the Mira stars and yet it is a highly atypical object. It was first detected in the OH ground state at 1665 MHz in 1975, but stopped emitting for about 15 years. In the 1990's, it underwent an OH eruptive event leading to long lasting 1665 MHz emission and also to intermittent 1667 MHz emission in mid-1992, and finally faded away in early 1999. After another 10 years of non-emissivity, in November 2009 we detected with the Nançay Radio Telescope (NRT) a new outburst in the OH 1665 MHz line towards Mira Ceti. This prompted us to start frequent monitoring of this source with the NRT, and to apply for a EVN-MERLIN ToO which led to a successful phase-referenced observation in February 2010. The superb angular resolution achieved with the EVN in February 2010 allowed us to locate the maser at 200 mas (∼26 AU) east of *o* Ceti.

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## 1. Introduction

*o* Ceti (a.k.a "*o* Cet", "Mira Ceti", "Mira A" or simply "Mira") is known as the prototype of "Miras" and "Mira-type" long-period variable stars. *o* Ceti has a typical optical period of 332 days; nevertheless, it is quite a remarkable Mira. It belongs to a detached binary system (Mira AB) in which mass transfer by wind interaction is taking place. *o* Ceti and its companion Mira B are separated by only $\sim$75 AU (Karovska et al. [1]). Also, *o* Ceti shows clear signs of stellar asymmetry (Karovska et al. [1], Reid & Menten [2]). Its distance has been estimated by HIPPARCOS to be 131 $\pm$18 pc and its proper motion is $PM_{RA} = +9.33$ mas yr$^{-1}$ and $PM_{Dec} = -237.36$ mas yr$^{-1}$ (van Leeuwen [3]). While SiO masers (originating close to the star, cf. Cotton, Perrin & Lopez [4]), $H_2O$ masers (originating at short distances in the circumstellar shell, cf. Bowers & Johnston [5]) and OH masers (originating in the outer part of the circumstellar shell) are commonly found towards isolated Miras, they are fairly unusual around binaries as is the case for the Mira AB system. Nevertheless, if the SiO and $H_2O$ maser emissions towards *o* Ceti show rather typical variabilities, the OH maser emission has proved to be highly non-standard. This could be due to its close association with Mira B, which is likely to affect the outer part of the circumstellar envelope. OH maser emission was first discovered in 1974, but only in the OH ground-state line at 1665 MHz (Dickinson et al. [6]). Then it ceased to emit for more than 10 years, but was finally detected again, in the same transition and similar velocity range in November 1990 (Gérard & Bourgois [7]), and faded away in early 1999.

In November 2009, after another 10 years of non-emissivity, *o* Ceti showed a new outburst in the 1665 MHz OH maser line. We present here the preliminary observational results of this exceptional event based on combined single-dish monitorings and interferometric observations, and compare them with the previous outburst recorded in the 1990's.

## 2. Observations

The results presented here are based on a series of complementary observations. The single-dish OH observations of the ground-state line at 1665 MHz were obtained with the NRT (Nançay Radio Telescope). The single-dish $H_2O$ observations at 22 GHz were taken with the Medicina 32-m antenna. Both the OH and $H_2O$ observations are part of ongoing Key Projects at the aforementioned instruments. Finally, the OH phase-referenced interferometric observations were taken the 28th of November 1995 and 4th of May 1998 (with MERLIN) and the 10th of February 2010 (with EVN-MERLIN).

## 3. Results

After having experienced 2 flares in the OH ground-state line at 1665 MHz, detected in the mid-1970's and the 1990's, *o* Ceti is presently experiencing a new outburst of emissivity in this transition. The outburst was detected with the NRT in November 2009 in its early stage (i.e., within $\simeq$ one month after its actual start) and rose to 4 Jy in late-January 2010.



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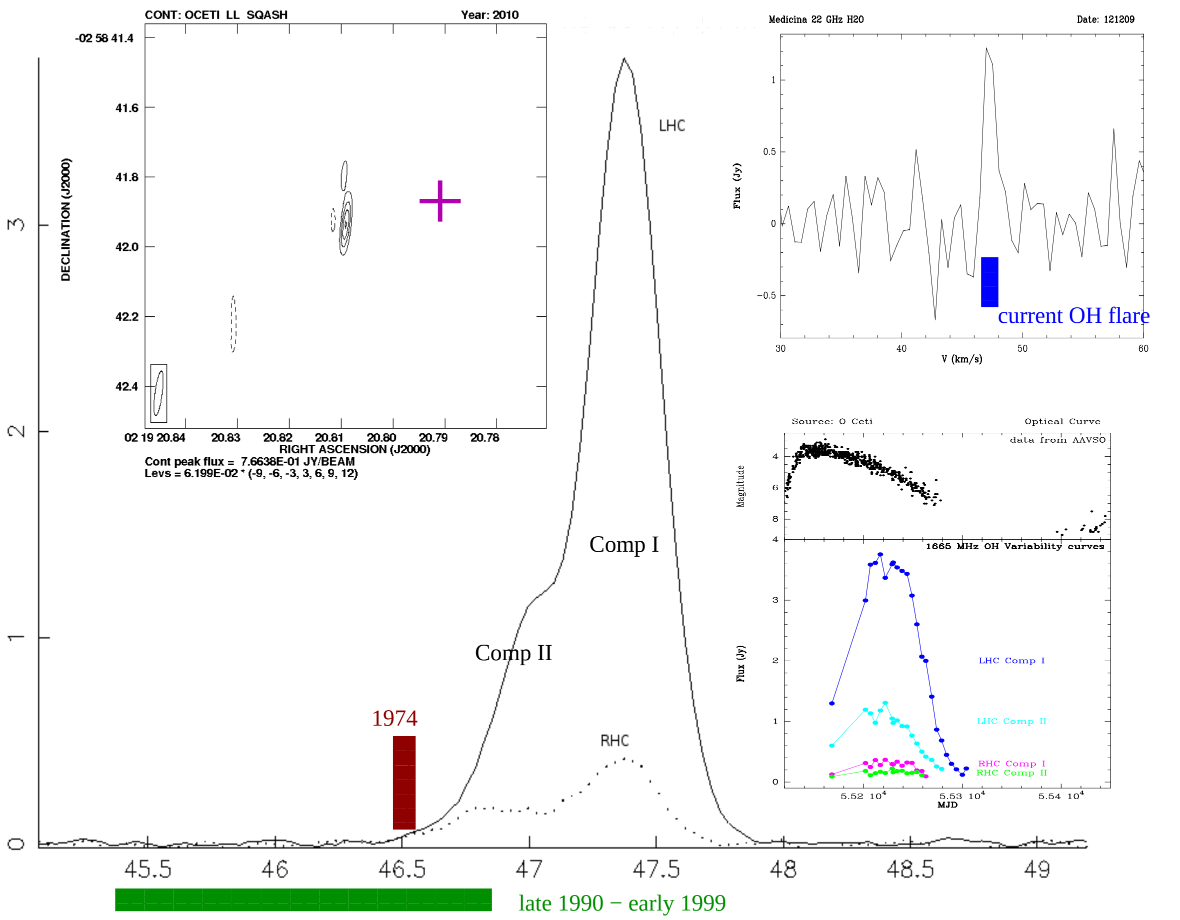


**Figure 1:** Main panel: average NRT spectrum of the current OH outburst in Mira Ceti at 1665 MHz (December 2009 - February 2010). The vertical bar gives the position of the OH maximum in 1974, and the horizontal bar gives the OH emission velocity spread in 1990-1999. Top-left insert panel: EVN-MERLIN map of the outburst taken in February 2010. The cross gives the estimated position of *o* Ceti, extrapolated from Matthews & Karovska's [11] position and taking into account the proper motion. Top-right insert panel: Medicina $H_2O$ maser emission during the rise of the OH maser emission towards the maximum in December 2009. The vertical bar gives the current OH emission velocity spread. Lower-right insert panel: Variability curves of the individual components after Gaussian spectral decomposition.

The central panel of Fig. 1 shows the average NRT spectrum of the OH outburst for all the spectra taken between December 2009 and February 2010 inclusive. The new emission, composed of 2 strongly polarised main spectral components, presents a profile and velocity spread similar to what was observed in the 1990's outburst, but it is now centred at V$\simeq$ +47.1 km/s (and spans the velocity interval V=[+46.4,+47.8] km/s), while in the 1990's the outburst emission was centred at V$\simeq$ +46 km/s (and spanned the velocity interval V=[+45.3,+46.8] km/s, cf. Fig. 2 top-left panel).

Figure 1, lower-right insert panel, shows the OH variability curves of the individual components after a Gaussian spectral decomposition has been performed following the method developed by Etoka & Le Squeren ([8]). All the components follow the optical light curve with a typical phase delay of 10-15% ($\sim$30-50 days). The components “Comp I” LHC and RHC peak at V$\simeq +47.4$ km/s and the components “Comp II” LHC and RHC peak at V$\simeq +47.0$ km/s and V$\simeq +46.8$ km/s respectively.

The OH and $H_2O$ masers are being monitored regularly with the NRT and the Medicina antenna respectively. This allowed us to make a direct comparison of the spectral profiles: both maser species are emitting in similar velocity ranges (cf. Fig. 1 top-right insert panel). This suggests that the outburst of OH maser emission originates from a region closer to the star than the distance of OH maser emission in the standard model. This is in agreement with the location of OH flaring events deduced from studies of several stars by Etoka & Le Squeren ([9], [10]).

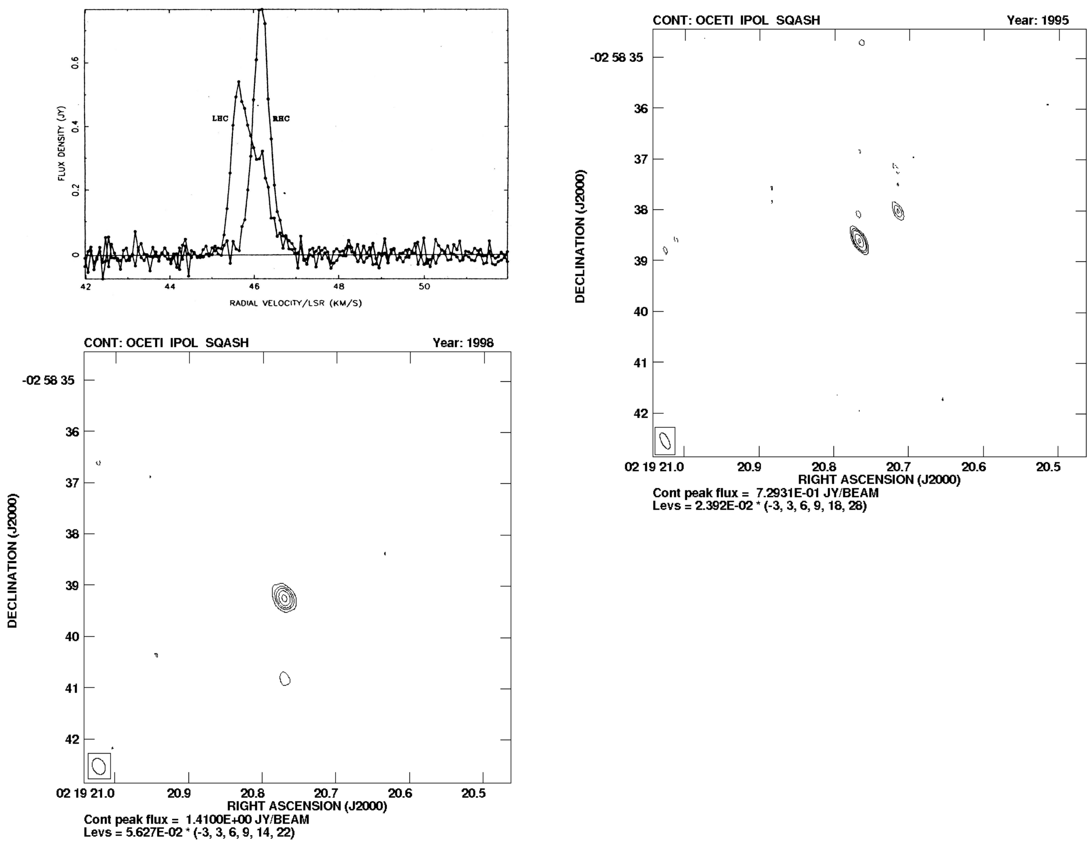


**Figure 2:** Top-left panel: average NRT spectrum of the OH flare at 1665 MHz during the 1990’s (Gérard & Bourgois [7]). Top-right panel: MERLIN observations in 1995. Lower-left panel: MERLIN observations in 1998 taken 2 years and 5 months after the first observation presented in the top-right panel. The difference in position of the strongest maser spot between the 1995 and the 1998 observations is: $\delta_{\rm RA} \simeq +58.5$ mas $\delta_{\rm Dec} \simeq -680$ mas

The first map of the latest outburst, obtained as an EVN-MERLIN ToO around the OH maximum in February 2010, is presented in Fig. 1 top-left insert panel. The cross gives the estimated position of *o* Ceti, extrapolated from Matthews & Karovska's [11] position and taking into account the proper motion. The current flaring region is located only ∼200 mas (i.e., ∼ 26 AU) east of *o* Ceti.

Two epochs of interferometric observations with MERLIN were taken in 1995 and 1998, 2 years and 5 months apart. The resulting maps are presented Fig. 2 (top-right and lower-left panels respectively). In 1995 two maser spots were detected separated by about 1 arcsec, while only one maser spot was detected in 1998. Between the 2 epochs of observation the difference in position of the strongest maser spot has been measured to be $\delta_{\rm RA} \simeq +58.5$ mas $\delta_{\rm Dec} \simeq -680$ mas, while a proper motion of $\delta{\rm PM}_{\rm RA} \simeq +22.5$ mas and $\delta{\rm PM}_{\rm Dec} \simeq -574$ mas is expected. This would lead to an actual separation of ≃110 mas (∼13 AU) between the 2 strongest maser spots observed in 1995 and 1998.

The first MERLIN observations in 1995 and the EVN-MERLIN observations of the current flare were obtained 14 years 2 months apart. Therefore, a proper motion of $\delta{\rm PM}_{\rm RA} \simeq +0.132$ arcsec and $\delta{\rm PM}_{\rm Dec} \simeq -3.36$ arcsec is expected. The difference measured between the position of the maser spot observed now and the strongest one in the 1995 map is $\delta_{\rm RA} \simeq +0.621$ arcsec $\delta_{\rm Dec} \simeq -3.24$ arcsec, while it is $\delta_{\rm RA} \simeq +1.35$ arcsec $\delta_{\rm Dec} \simeq -3.84$ arcsec with respect to the faintest spot in the 1995 map. The current maser position is consequently offset from the positions of the stronger and fainter maser spots observed in 1995 by 0.5 and 1.3 arcsec, respectively. This is significantly greater than the uncertainties and implies that the outburst in the 1990's and the current one originate from 2 distinct regions.

Knapp et al. ([12]) estimated the stellar velocity to be $V = +46.6 \pm 0.2$ km/s (from CO(3-2) emission). With such a stellar velocity, it would mean that the previous outburst in the 1990's, but also in the mid-1970's (centred at $V \simeq +46$ km/s and $+46.5$ km/s respectively) were located in the front cap of the shell while the current outburst (centred at $V \simeq +47.1$ km/s) would be located in the rear cap of the shell. However, the stellar velocity estimate has to be taken with caution due to the asymmetrical nature of the CO(3-2) profile.

## 4. Discussion & Conclusion

We have presented here the preliminary observational results of the current OH eruptive event in Mira Ceti. There are indications that this emission is located relatively close to the central star itself. A comparison with the previous outburst recorded in the 1990's indicates that the regions of these episodic events are distinct.

In order to understand the nature of these recursive events several questions are to be addressed:

- Where is the OH flaring region in relation to the $H_2O$ envelope and the stellar surface?
- Where is the flaring region in relation to Mira B ?

- How does the flaring region evolve dynamically over time?
- Is the flare associated with either an (unusual) stellar activity and/or with the Mira A-B interaction?
- Did the triggering agent of the OH flare also affect other more internal parts of the circumstellar shell (in particular, the $H_2O$ and the SiO envelopes)?

To address these questions, a series of complementary observations (e.g., with eMERLIN/EVN, the VLBA and ALMA) are needed so as to:

- determine the absolute astrometric positions of the stars of the system;
- characterise the physical and dynamical properties of the inner part of the circumstellar shell up to and including the outburst region itself;
- characterise the stellar surface itself in order to identify any (unusual) stellar activity or properties.

**Acknowledgments**
This paper is dedicated to the memory of Jim Cohen who was the PI of the 1995 and 1998 MERLIN observations and also in recognition of his major contribution to this field in general.

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