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The extraordinary outburst in NGC6334I-MM1: dimming of the hypercompact HII region and destruction of water masers

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Abstract. We present subarcsecond resolution pre- and post-outburst JVLA continuum and water maser observations of the massive protostellar outburst source NGC6334I-MM1. The continuum data at 5 and 1.4 cm reveal that the free-free emission powered by MM1B, modeled as a hypercompact HII region from our 2011 JVLA data, has dropped by a factor of 5.4. Additionally, the water maser emission toward MM1, which had previously been strong (500 Jy) has dramatically reduced. In contrast, the water masers in other locations in the protocluster have flared, with the strongest spots associated with CM2, a non-thermal radio source that appears to mark a shock in a jet emanating $2''$ (2600 au) northward from MM1. The observed quenching of the HCHII region suggests a reduction in uv photon production due to bloating of the protostar in response to the episodic accretion event.

Keywords. Massive protostars, accretion, masers

1. Introduction

Episodic accretion in protostars is increasingly recognized as being an essential phenomenon in star formation (Kenyon *et al.* 1990, Evans *et al.* 2009). The total luminosity of a protostar scales with the instantaneous accretion rate, so variations in that rate will lead to observable brightness changes (e.g., Offner & McKee 2011). Direct evidence for episodic accretion events towards massive protostars have recently emerged via dramatic increases in the brightness, and hence luminosity observed in the near-IR towards S255IR-NIRS3 (Caratti o Garatti *et al.* 2016), as well as in the millimeter toward NGC6334I-MM1 (Hunter *et al.* 2017a). The impact of such an accretion event on the free-free emission from a massive protostar is as yet relatively unexplored, though Hosokawa & Omukai (2009) (for example) suggest that significant suppression of uv-photons is expected.

Another eruptive phenomenon associated with sites of high mass star formation are maser flares, such as the three past events observed in the water masers in the vicinity of Orion KL (Abraham *et al.* 1981, Omodaka *et al.* 1999, Hirota *et al.* 2014). The repeating nature of the Orion maser outbursts (Tolmachev 2011) as well as the periodic

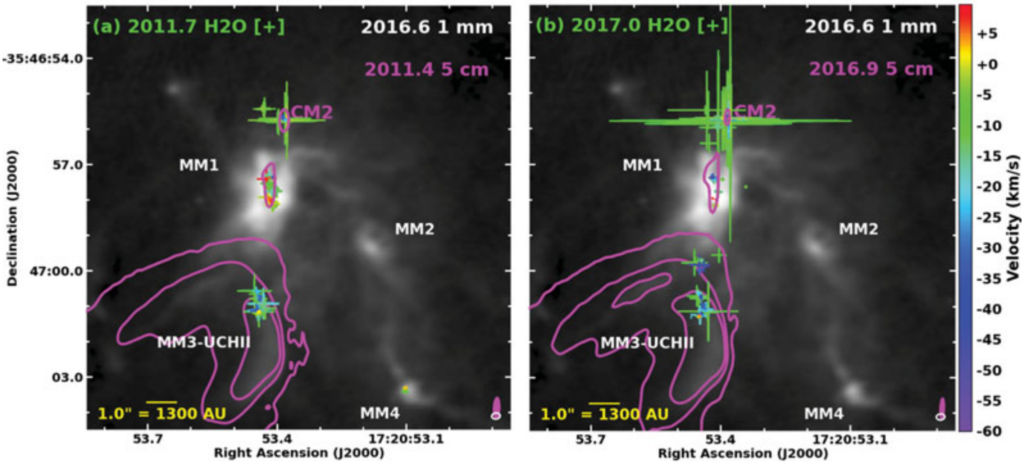

Figure 1. (a) Water maser positions (+ symbols) from epoch 2011.7 (Brogan *et al.* 2016) are overlaid on an epoch 2016.6 ALMA 1 mm continuum image (Hunter *et al.* 2017a). Epoch 2011.5 JVLA 5 cm continuum contours are also overlaid with contour levels of $3.7 \times 10^{-5} \times$ (4, 260, and 600). Maser intensity is indicated by the size of the symbol, while velocity is indicated by the color. Continuum sources are labeled for reference; sources with millimeter emission are labeled in white. (b) Same as (a) but the epoch 2016.9 5 cm emission contours are shown (contour levels $2.2 \times 10^{-5} \times$ (4, 260, and 600)), along with the 2017.0 water maser positions. In both panels, the size of the symbol is $\propto$ flux density$^{0.5}$, and the synthesized beams are shown in the lower right.

features seen toward many high mass protostellar objects (HMPOs) in the 6.7 GHz methanol maser line (e.g. Goedhart *et al.* 2004, MacLeod & Gaylard 1996), have suggested that variations in the underlying protostellar activity could be responsible for the maser flares. Indeed, the recent methanol maser flare associated with the infrared outburst in S255IR-NIRS3 (Moscadelli *et al.* 2017), and the emergence of methanol masers toward the (sub)millimeter outburst in NGC6334I-MM1 (Hunter *et al.* 2017b) have provided the first direct link between protostellar accretion outbursts and maser flares. Detailed study of additional maser species is of critical importance to understanding accretion process in high-mass protostars.

In this proceeding, we describe multi-epoch results from subarcsecond resolution Karl G. Jansky Very Large Array (VLA)† observations of the centimeter-λ emission and 22.235 GHz H_2O maser emission toward the millimeter outburst source NGC6334I-MM1 (Hunter *et al.* 2017a). NGC6334I is a protocluster forming massive stars (Hunter *et al.* 2006) at a distance of 1.3 ± 0.1 kpc (Chibueze *et al.* 2014, Reid *et al.* 2014). Its massive constituents include a more evolved UCHII region (MM3), two millimeter bright cores, MM1 and MM2, each of which contain multiple massive protostars as well as copious hot core line emission, and a line poor but millimeter-bright massive dust source MM4 (Brogan *et al.* 2016). One of the massive protostars in MM1, MM1B has already formed a hypercompact HII region (Brogan *et al.* 2016), and in 2015 appears to have undergone a significant episodic accretion event resulting in a large (factor of ~70) increase in its luminosity (Hunter *et al.* 2017a).

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2. Results

Figure 1 shows the pre-outburst (epoch 2011.4) and post-outburst (epoch 2016.9) 5 cm continuum emission, as well as the locations of the 2011.7 and 2017.0 epoch H_2O masers superposed on an ALMA 2016.6 1 mm image of the dust continuum emission toward NGC6334-I. We find that the 5 cm emission is not significantly changed between the pre- and post-outburst epochs (the most apparent differences are due to the lower image fidelity of the 2011 data). Of particular note is the persistence of the non-thermal source CM2, located $\sim 2''$ (2600 au) north of the origin of the millimeter outburst MM1-B. The nature of this source, which appears to be completely devoid of dust emission from our sensitive 1 mm ALMA data, is a mystery. Indeed, this source has not been detected shortward of 5 cm. Its location along the same axis as a 5 cm jet emanating from MM1-B suggests that it is a related shock structure.

In contrast, the H_2O maser data shows considerable differences: (i) the maser emission has significantly flared toward the mysterious non-thermal source CM2; (ii) the emission toward MM1 has significantly decreased in both flux density and spatial extent; (iii) a number of new maser regions are detected toward the northern part of the UCHII region MM3; and (iv) the weak masers detected toward MM4 in the 2011.4 epoch are no longer detectable in the 2017.0 epoch. Based on single dish monitoring of the water maser emission in this source from the HartRAO 26m telescope over the last decade (MacLeod *et al.* 2018), a major water maser flaring event began in early 2015 (presumably marking the start of the accretion event). The JVLA data presented here localize the flare to the location of CM2 for the first time.

Figure 2 shows a close-up view of the pre- and post-outburst H_2O maser activity toward MM1, as well as contours of pre- and post-outburst 1.5/1.35 cm continuum emission. This figure demonstrates both the significant decrease in water maser activity toward MM1 post-outburst, and a dramatic drop in free-free continuum emission from the hypercompact HII region MM1B, while the emission from MM1D has remained constant. We suggest that changes in the physical conditions in the vicinity of MM1B due to the accretion event have disrupted much of the water maser activity. A potential culprit is the increase in dust temperature that accompanied the outburst (Hunter *et al.* 2017a).

To further assess 1.5/1.35 cm dimming, we fit two-dimensional Gaussian models to each source, and after interpolating the measurements to a common frequency using the spectral index of each object, we find that the flux density of MM1D at 1.5 cm has remained constant to within 10%, giving confidence in the relative flux scaling between the 2011.4 and 2017.0 datasets. In contrast, the flux density at 1.5 cm of the hypercompact HII region MM1B has dropped by a factor of ~ 5.4 during this interval. The pre-outburst 1.5 cm emission from MM1B (epoch 2011.4, 1.78 ± 0.11 mJy) is consistent with an ionizing photon rate (Q) of $10^{43.94}$ s^{-1} (using Eq. 6 of Turner & Matthews 1984). This value of Q is consistent with a zero age main sequence (ZAMS) stellar surface temperature of 19500 K (Diaz-Miller *et al.* 1998), which in turn corresponds to a ZAMS spectral type of B2.7, mass of 5.6 $M_\odot$ and radius of 3.2 $R_\odot$ (Hanson *et al.* 1997). The observed dimming of the 1.35 cm emission in epoch 2017.0 requires a lower stellar temperature, while the luminosity increase requires a larger radius by a factor of 10 (i.e. up to 32 $R_\odot$), a combination that is equivalent to a B3.4 supergiant star. This level of stellar bloating in response to a rapid increase in accretion rate is predicted by Hosokawa & Omukai (2009) (also see Inayoshi *et al.* 2013) for an accretion rate of 10^{-3} $M_\odot$ yr^{-1}. Future subarcsecond JVLA monitoring of the centimeter wavelength emission at 1.35 and 0.7 cm will help to further characterize how this emission will evolve with time and, consequently, how the underlying protostar's properties continue to respond to the accretion event.

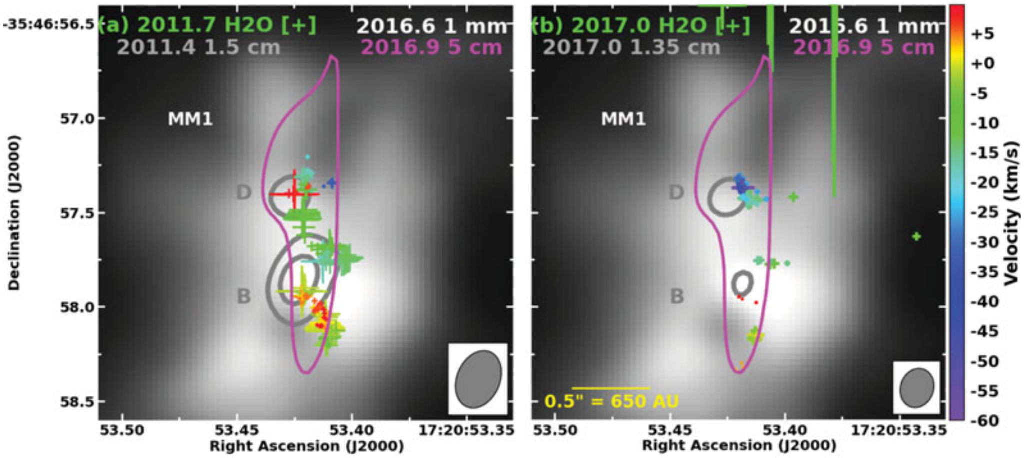

Figure 2. Similar to Fig. 1, except showing a smaller field of view toward MM1, note both panels show the 5 cm 2016.9 continuum contours. In (a) 1.5 cm epoch 2011.4 continuum contours are also overlaid (thicker contours) at levels of $7.2 \times 10^{-5} \times (4, 10)$ Jy beam^{-1} (the beam is shown in the lower right). In (b) 1.35 cm epoch 2017.0 continuum contours are overlaid at $4.4 \times 10^{-5} \times (4)$ Jy beam^{-1} (the beam is shown in the lower right). In both panels, the size of the symbol is $\propto$ flux density$^{0.5}$. For reference the LSR velocity of this source is about -7 km s^{-1} (McGuire *et al.* 2017, Zernickel *et al.* 2012).

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