# First disk-mediated accretion burst from a massive protostar

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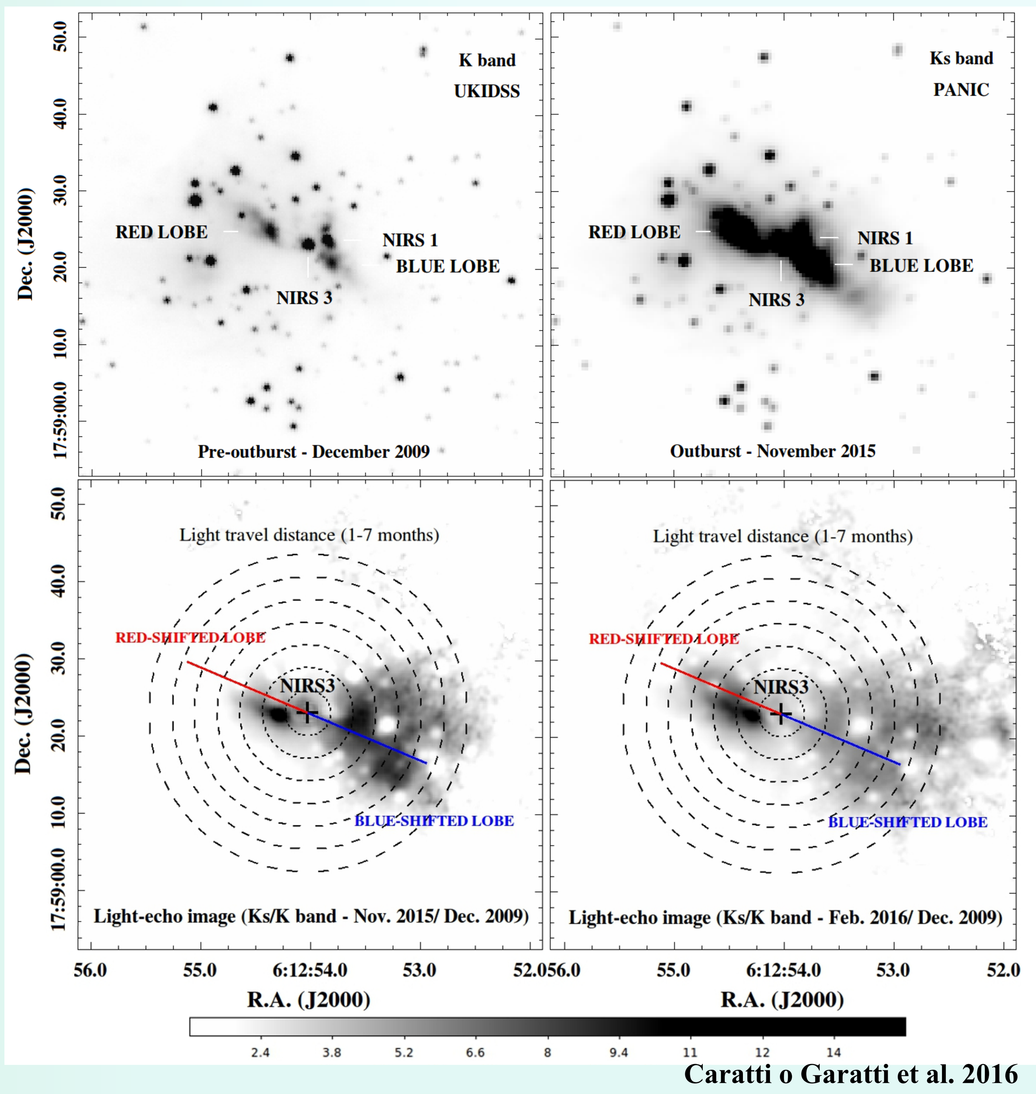
**Abstract:** We report on the discovery and follow-up of the first disk-mediated accretion burst in a high mass YSO (HMYSO), S255IR NIRS 3 ($M_*$~20$M_\odot$, $L_{bol}$=2.4x10$^4$ $L_\odot$, Wang et al. 2011, Zinchenko et al. 2015). Our NIR images show the brightening of the central source and its outflow cavities. NIR spectroscopy reveals emission lines typically observed in low-mass disk-mediated accretion bursts (namely EXor bursts), but orders of magnitude more luminous. The HMYSO luminosity increased by 1.3x10$^5$ $L_\odot$, corresponding to an $\dot{M}_{acc}$ increment of 5x10$^{-3}$ $M_\odot$ yr$^{-1}$ (Caratti o Garatti et al. 2016). The accretion burst triggered Class II $CH_3OH$ maser flares (at 6.7GHz), reported in November 2015 (Fujisawa et al. 2015, Stecklum et al. 2016), excited through IR pumping (Moscadelli et al 2017). Finally, through JVLA monitoring, we also detect a radio burst starting about 14 months after the accretion burst (Cesaroni et al. in prep.). The radio emission is modelled with a fast (900 km s$^{-1}$) expanding radio jet and latest images reveal a new knotty structure. This suggests that the radio jet has been boosted by a sudden increase in the mass loss rate, which is, in turn, a consequence of the accretion burst.

**Introduction:** The latest picture of low-mass young stellar objects (YSOs) evolution suggests that most of the accreted material is gathered during outbursts (see Audard et al. 2014). During these outbursts (FUor and EXor bursts), the mass accretion rate ($\dot{M}_{acc}$) increases by several orders of magnitude (up to ~10$^{-4}$ $M_\odot$ yr$^{-1}$), and, as a consequence, in a few months the YSO brightness also increases by several magnitudes (up to 6 mag) at optical and near-infrared (NIR) wavelengths, whereas augmented mass ejection rates are also expected. Moreover, such bursts take place through a broad range of stellar masses and during the whole low-mas YSO evolution (e.g., Caratti o Garatti et al. 2011, Contreras Peña et al. 2017). Such evidence was so far missing in HMYSOs.

## ACCRETION OUTBURST & LIGHT ECHO

**Figure 1:** ***Upper left:*** UKIDSS pre-outburst K-band (2.2 μm ) image (December 2009). NIRS 3 and its outflow cavities are observed. ***Upper right:*** PANIC outburst Ks-band image (November 2015), showing the brightening of NIRS 3 and its outflow cavities. ***Lower left:*** Ratio between PANIC and UKIDSS images. Concentric circles mark light travel distances in the plane of the sky separated by one month. The increment of brightness ratio towards the HMYSO represents the light echo. The echo asymmetry is mainly due to the outflow inclination. The light-echo analysis indicates that *the burst begun in June 2015*. ***Lower right:*** Ratio between PANIC Ks (February 2016) and UKIDSS K (December 2009) images showing the light-echo motion.




## SPECTRAL EVOLUTION OF THE OUTBURST

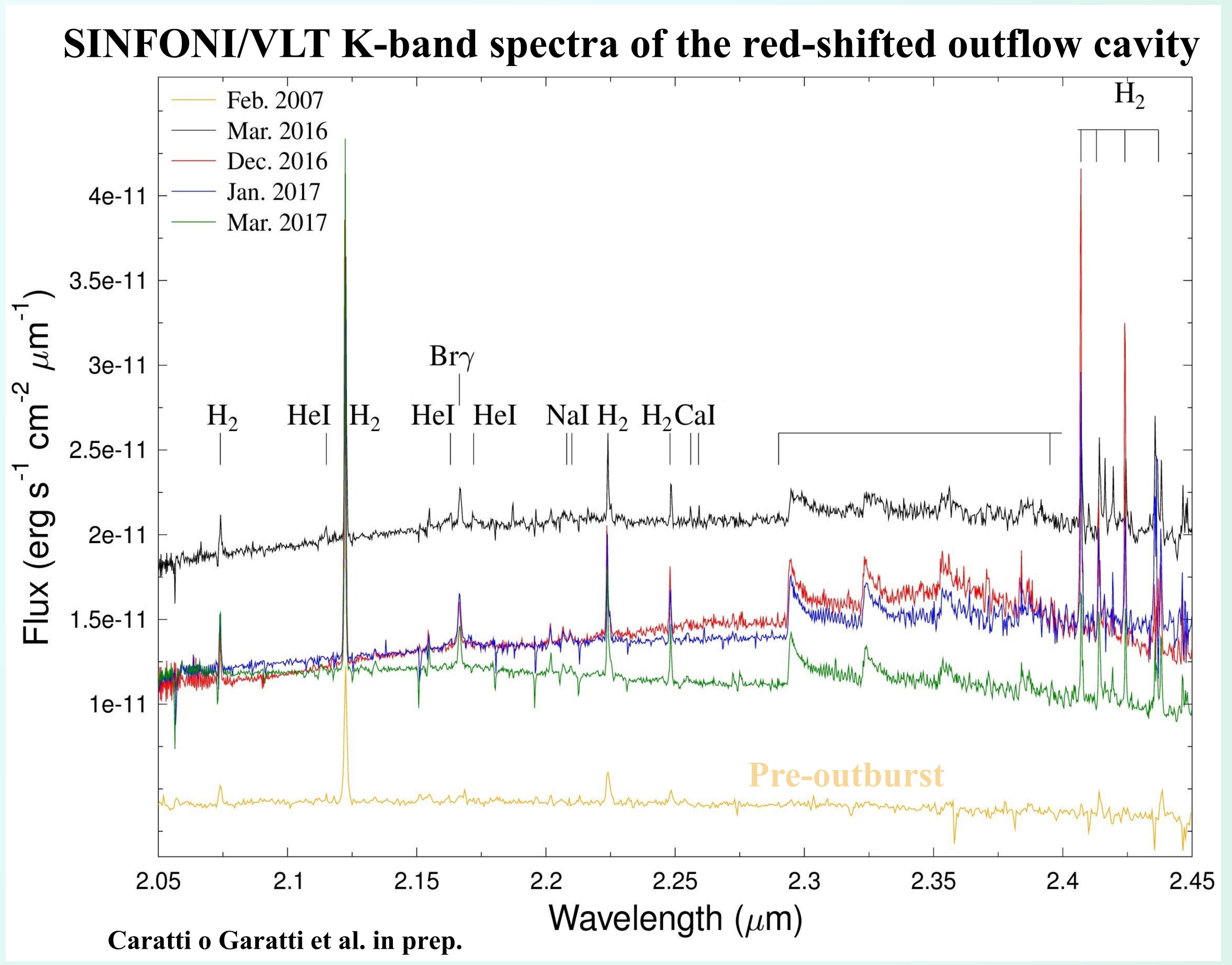
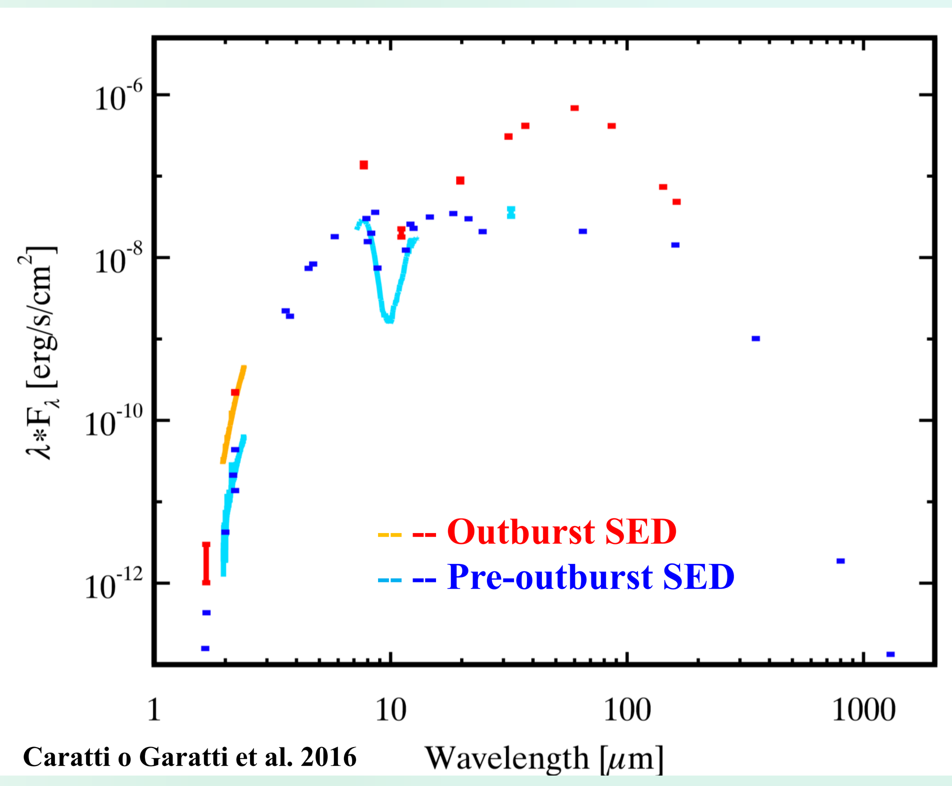



**Figure 2:** Pre-outburst (orange, Feb. 2007) and outburst multi-epoch K-band spectroscopy of the red-shifted outflow cavity of S255IR NIRS 3. The cavity acts as a mirror allowing to detect the disk emission. The pre-outburst spectrum only displays $H_2$ lines in emission, whereas the outburst spectra show emission lines typical of EXor bursts. The first-epoch burst spectrum (black, Mar. 2016) was taken ~9 months after the beginning of the event. It shows: CO band-heads, NaI doublet, CaI doublet lines originating from the outer layers of the disk atmosphere; HeI and HI lines emitted closer to the central source (~0.1 au) and tracing accretion onto the star and/or disk winds. An increase in brightness of the $H_2$ emission lines ($v_r$~0 km/s) likely UV-pumped by the strong radiation of the accretion shock is detected As the burst evolves, the He I lines disappear, the continuum flux decreases and the CO line shapes change, indicating the fading of the burst activity and cooling of the inner disk.

## SED & OUTBURST PARAMETERS




$L_{bol}$=(1.6 ± 0.3)x10$^5$ $L_\odot$
$\Delta L_{acc}$=(1.3 ± 0.4)x10$^5$ $L_\odot$
$\dot{M}_{acc}$=(5 ± 2)x10$^{-3}$ $M_\odot$/yr
($M_*$=20 $M_\odot$ & $R_*$=10 $R_\odot$)
Energy released ~ 10$^{46}$ erg
Accreted mass ~ 2 $M_{Jupiter}$

**Figure 3:** Pre- (cyan and blue) and outburst (orange and red) spectral energy distributions (SEDs) of S255IR NIRS 3. Dark colours indicate photometric measurements and light colours denote spectra. The pre-outburst SED was obtained by combining ESO/VLT, UKIDSS, SPITZER/IRAC and MIPS, MSX, AKARI, and BGPS. The outburst SED was obtained using data from PANIC, GROND, SINFONI, SOFIA/FORCAST and FIFI-LS taken in February 2016.

## ON SOURCE SPECTRA

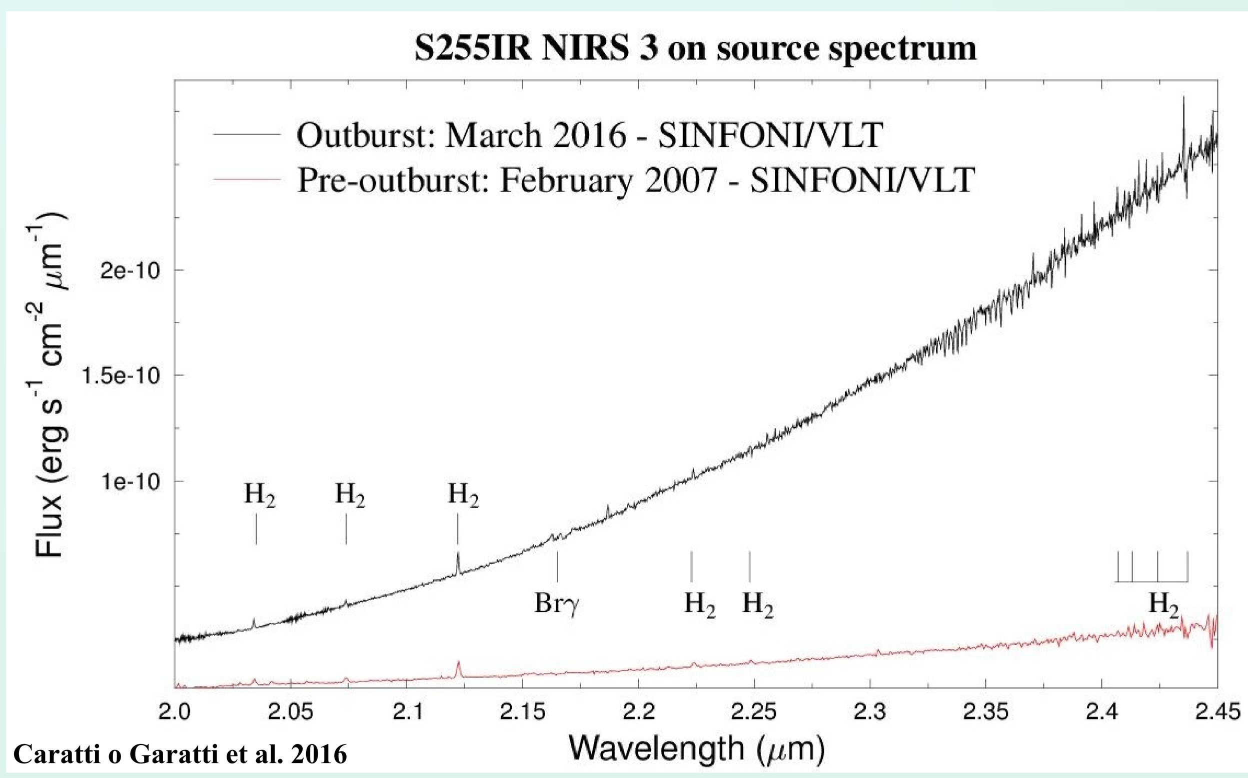



**Figure 4:** SINFONI/VLT pre- (red) and outburst (black) K-band spectra of S255IR NIRS 3. The burst spectrum is much brighter than that in the quiescent phase. The on source spectrum shows a very red and almost featureless continuum,. No photospheric features are detected. This along with the extremely reddened continuum is likely due to the strong veiling, caused by the accretion, and the high visual extinction ($A_V$~44 mag), resulting from the almost edge-on geometry of the disk.

## $CH_3OH$ MASER FLARE

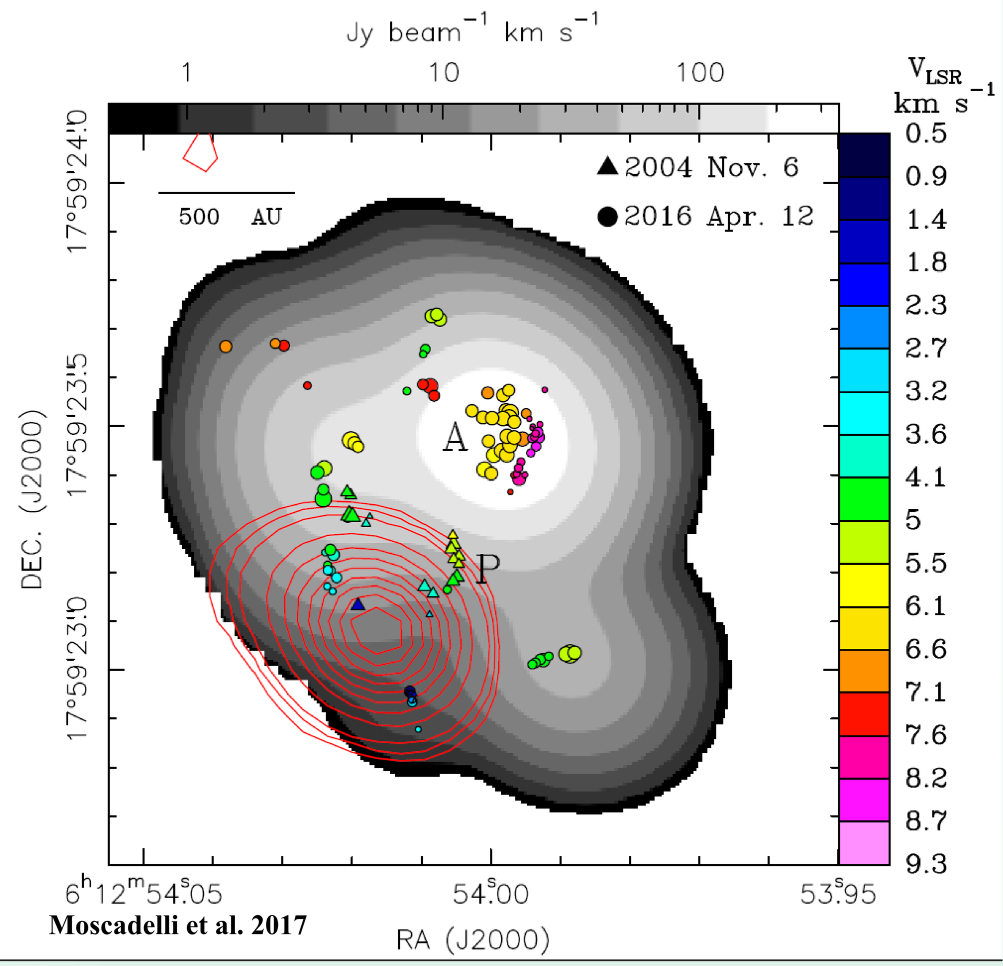
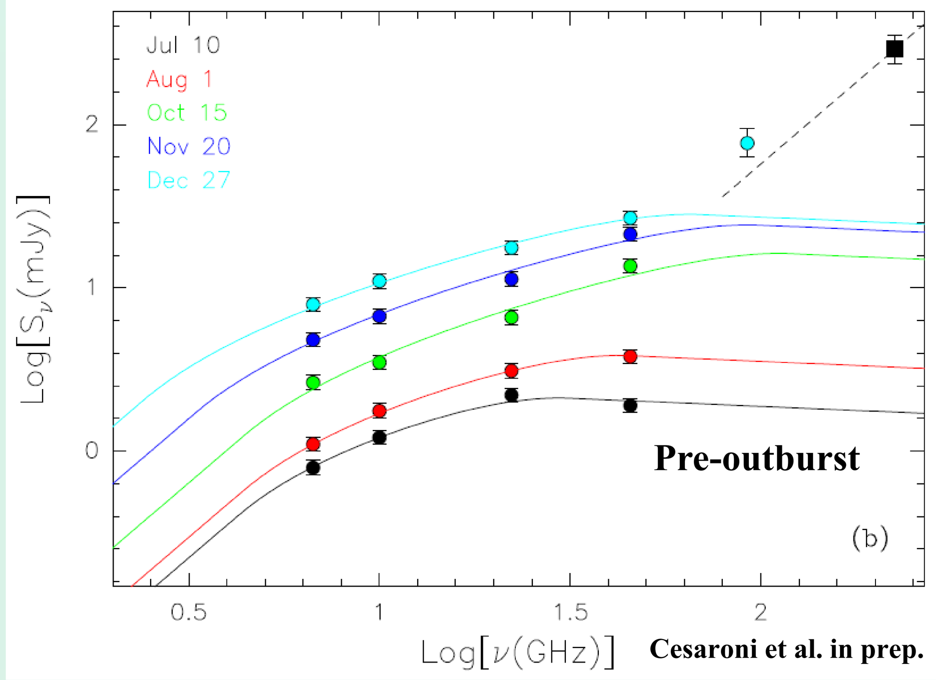



**Figure 5:** Distribution of the 6.7GHz $CH_3OH$ masers toward NIRS 3 (red contour levels) observed with the European VLBI Network (EVN). Circles and triangles represent maser spots before and after the outburst, respectively. The symbol size varies logarithmically with the maser brightness, and colours indicate the maser $V_{LSR}$ according to the right-hand scale. The apparent motion of the 6.7GHz $CH_3OH$ masers between the two epochs is negligible (Rygl et al. 2010). During the burst, the pre-burst maser cluster ("P") is no longer detected, whereas a new cluster ("A") appears, originating from a very extended (0.2"–0.3") maser plateau at 500–1000 au from the source. The new flaring masers emit across a more redshifted $V_{LSR}$ range and their emission extends over a larger area at larger separation from the HMYSO.

## RADIO BURST: ACCRETION TURNS INTO EJECTION

**Figure 6:** JVLA radio spectra of the continuum emission before (black circles) and during (coloured circles) the radio burst. The cyan point is a 3 mm ALMA measurement taken on December 2016. The black square is a pre-burst measurement at 1.3 mm (Zinchenko et al. 2012). The coloured curves are fits to the corresponding radio spectra obtained from the jet model of Reynolds (1986), assuming that the jet is expanding with a constant speed of 900 km s$^{-1}$. The dashed line is an extrapolation of the dust emission under the conservative assumption that the flux is ∝ $\nu^2$. The 3 mm flux density appears to exceed the pre-burst flux extrapolated from Zinchenko's measurement by an amount comparable to the expected free-free flux of the radio jet (cyan curve). This indicates that the free-free emission of the radio jet substantially contributes to the 3 mm flux density.



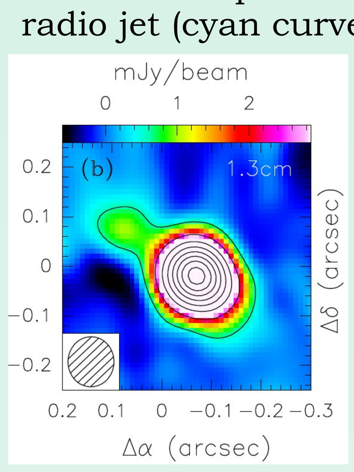




**Figure 7:** Map of the 1.3 cm continuum emission towards the central region NIRS3, obtained with the JVLA on December 27, 2016. The image has been saturated to emphasize the tail of emission pointing towards NE, i.e. towards the jet direction. This strongly suggests that we are resolving for the first time the expanding radio jet. The mean expansion speed obtained from the ratio between the jet size (~300 AU) and the time from the beginning of the outburst (June 2015), is ~ 900 km s$^{-1}$.

## Conclusions

S255IR NIRS 3 outburst has fundamental implications on our knowledge of the formation of early-type stars. The mere existence of such an accretion burst strongly favours models according to which massive stars form through disk-mediated accretion like their low-mass siblings. Our findings also suggest that accretion might not be continuous but rather episodic, implying disk fragmentation. Moreover such bursts have also a strong impact on the circumstellar environment, as seen in the methanol maser flare and the radio jet outburst.

**References:** Audard et al. 2014, PPVI, Un. Arizona Pr., 387; Caratti o Garatti et al. 2011, A&A 526, L1; Caratti o Garatti et al. 2016, Nature Phys. 13, 276; Contreras Peña et al. 2017, MNRAS 465, 3039; Fujisawa et al. 2015, ATel 8286; Moscadelli et al. 2017, A&A 600, L8; Reynolds 1986, ApJ 304, 713; Rygl et al. 2010, A&A 511, A2; Stecklum et al. 2016, ATel 8732, 1; Wang et al. 2011, A&A 527, 32; Zinchenko et al. 2012, ApJ 755,177; Zinchenko et al. 2015, ApJ 810,10.