A Wonder of Star Formation
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Watching a Massive Star Grow

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Valuable archive data thanks to Hans

Revealing the "missing" low-mass stars in the S254-S258 star forming region by deep X-ray imaging*★*

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A sharp view of the young high-mass star cluster S255-IR and its neighborhood★

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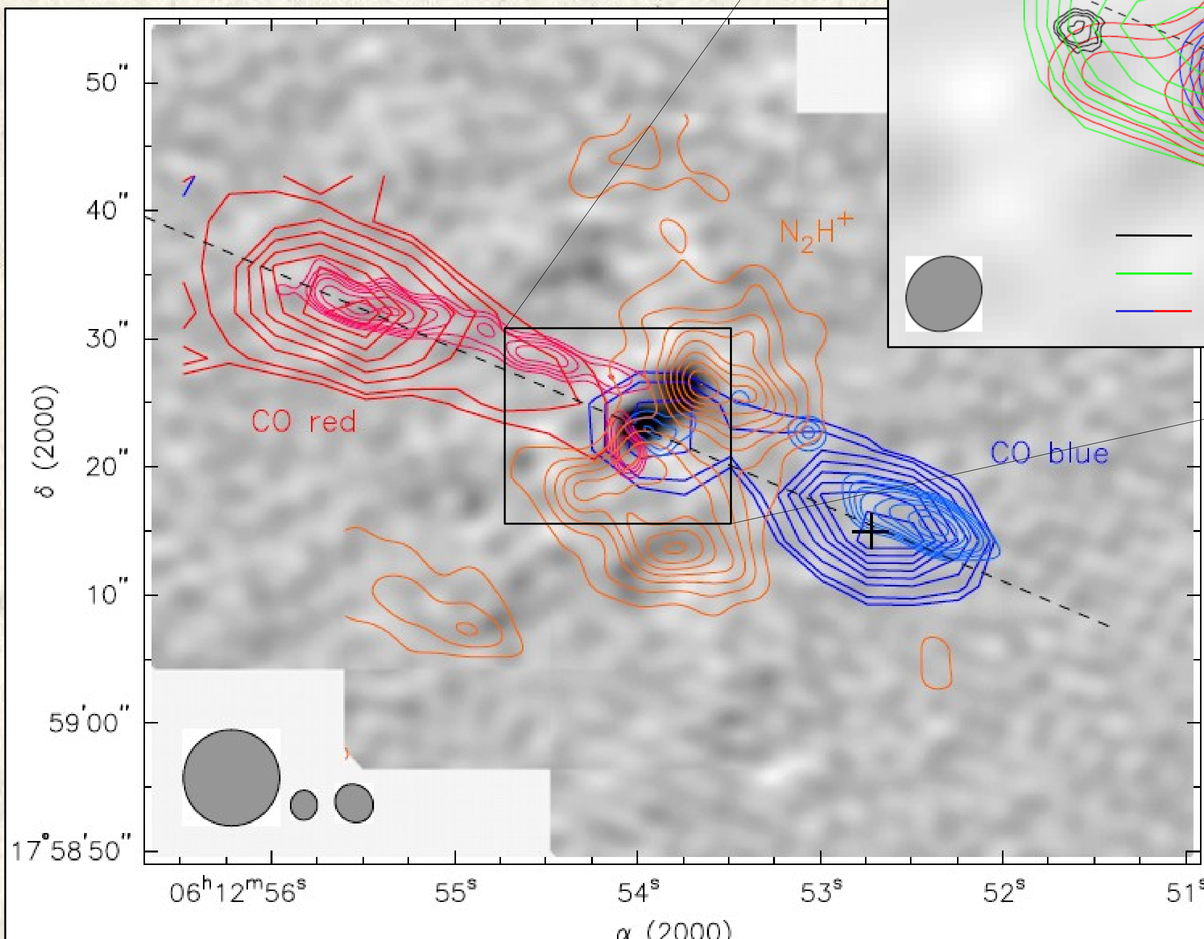
Introducing the HMYSO S255IR-NIRS3

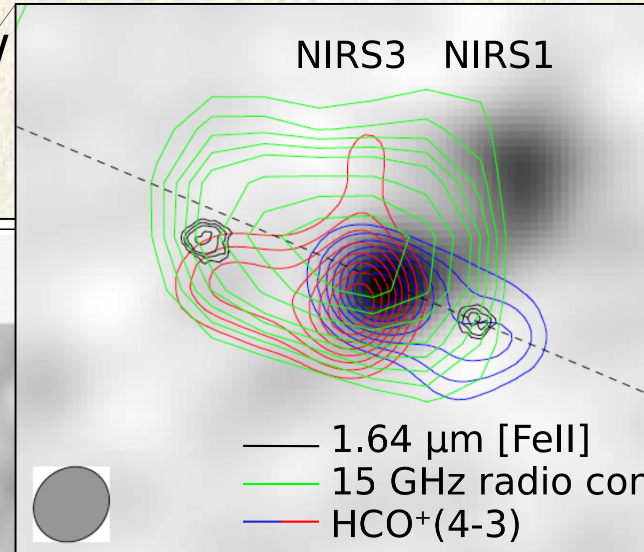
Well-studied HMYSO, $L_{*} \sim 3 \times 10^{4} L_{\odot}$, $M_{*} \sim 20 M_{\odot}$, disk/outflow system (Zinchenko+ 2015)

Extinction $A_V \sim 46$mag (Simpson+ 2009)

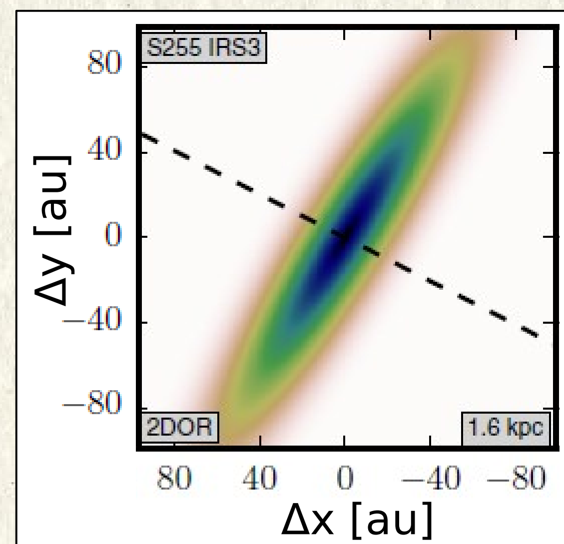
Evidence for three previous accretion/ ejection events within 7000 yr!

distance 1.78 ± 0.11kpc (Burns+ 2016)



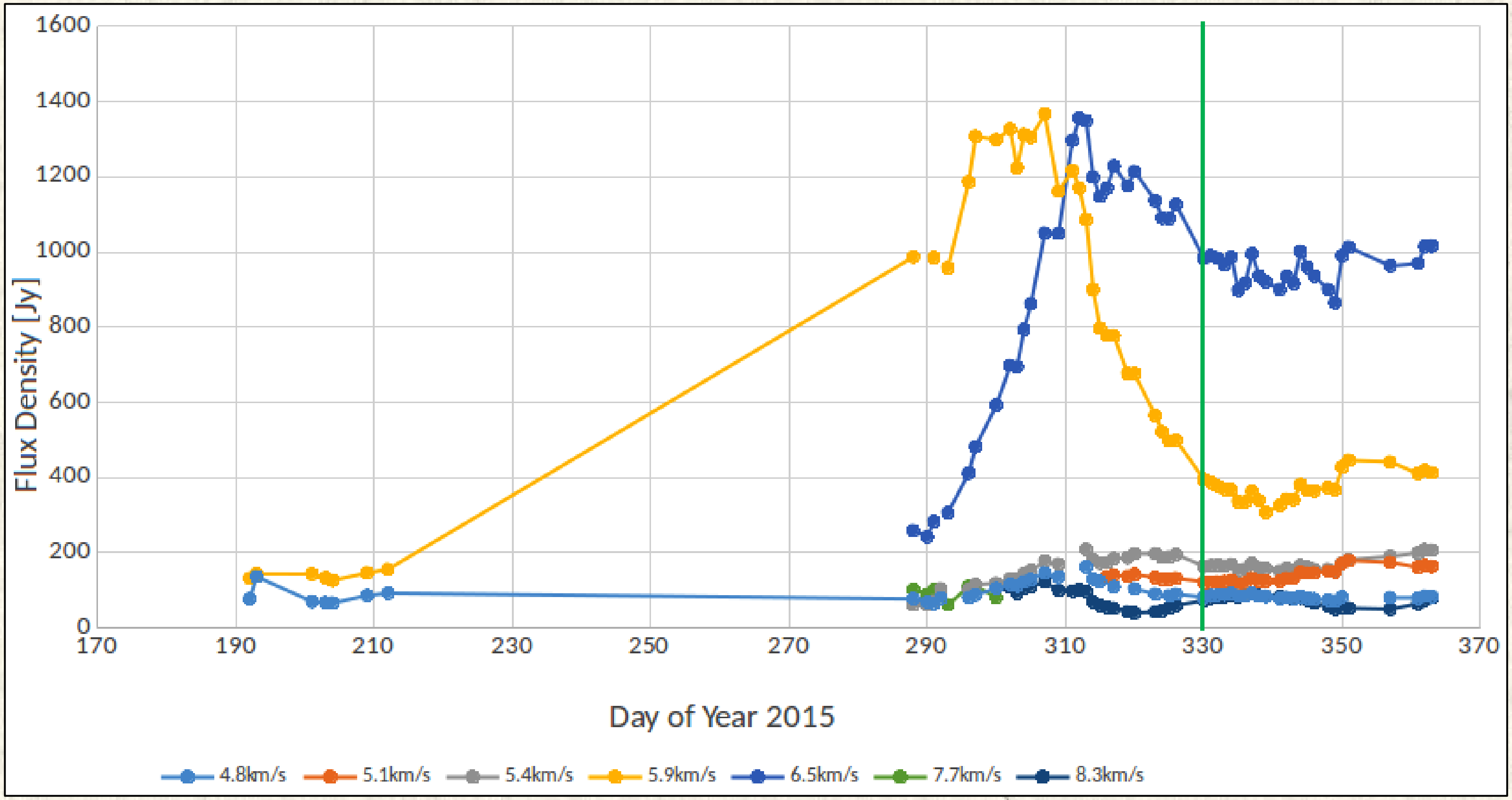


Brightness model for the 10.6µm VLTI visibilities (Boley+ 2013)



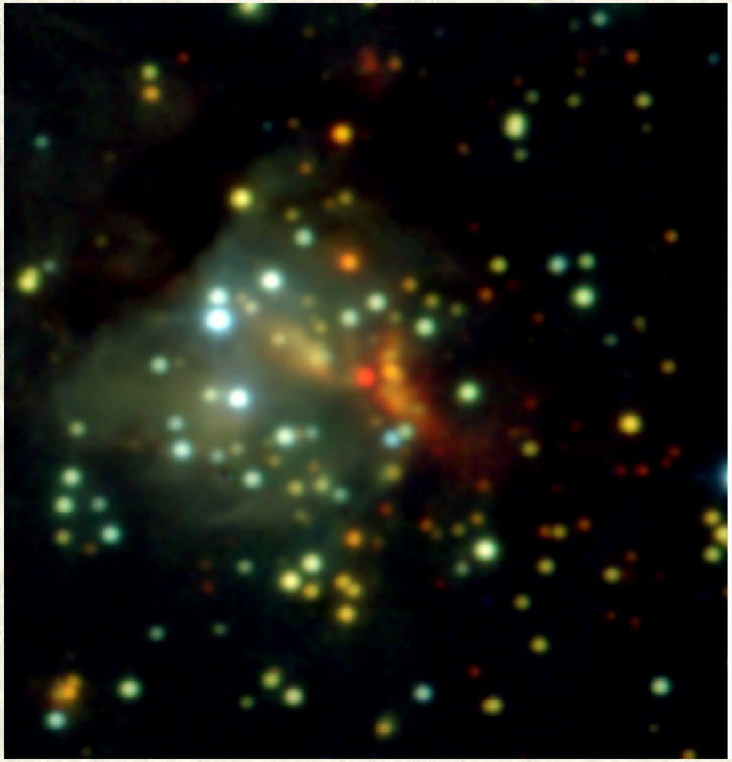
The Wakeup Call – The Methanol Maser Flare

Class II 6.7 GHz methanol masers are pumped by thermal IR emission (Sobolev+ 1997) and trace embedded luminous YSOs (Breen+ 2013). The methanol maser in S255IR was detected by Menten (1991) - its 2015 flare was the first one ever.

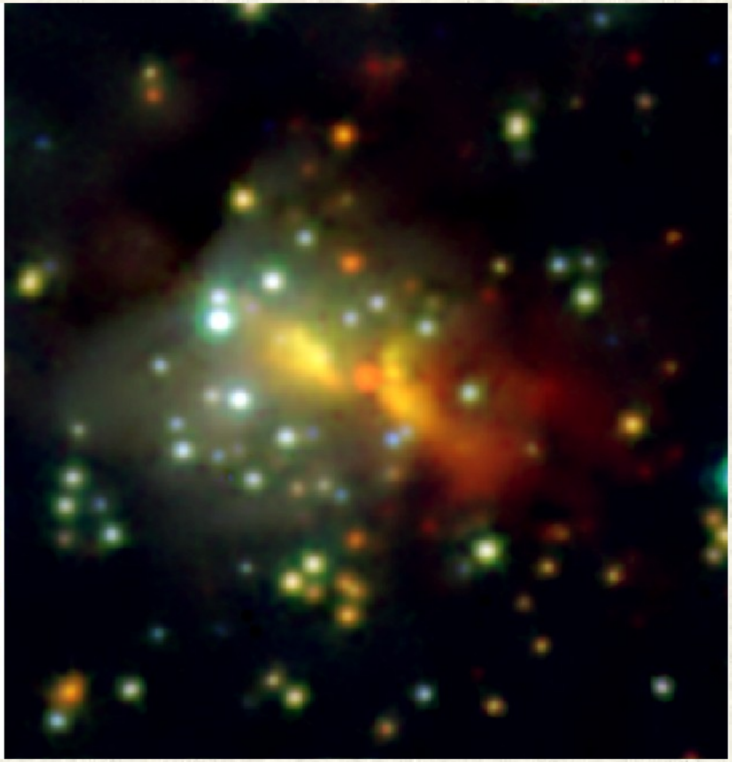


CH_3OH maser flux variations showing the **flare** of the **5.9km/s** component and the **emergence** of a new one at **6.2 km/s** (courtesy Fujisawa+ 2015). The **vertical** line marks the date of our first NIR imaging.

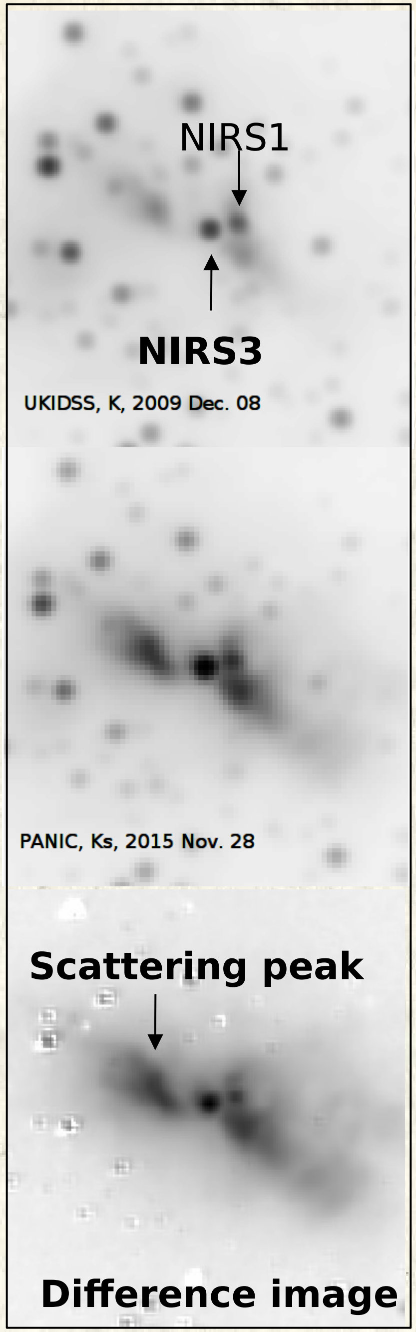
The Accretion Burst of S255IR-NIRS3



UKIDSS (Dec 2009)



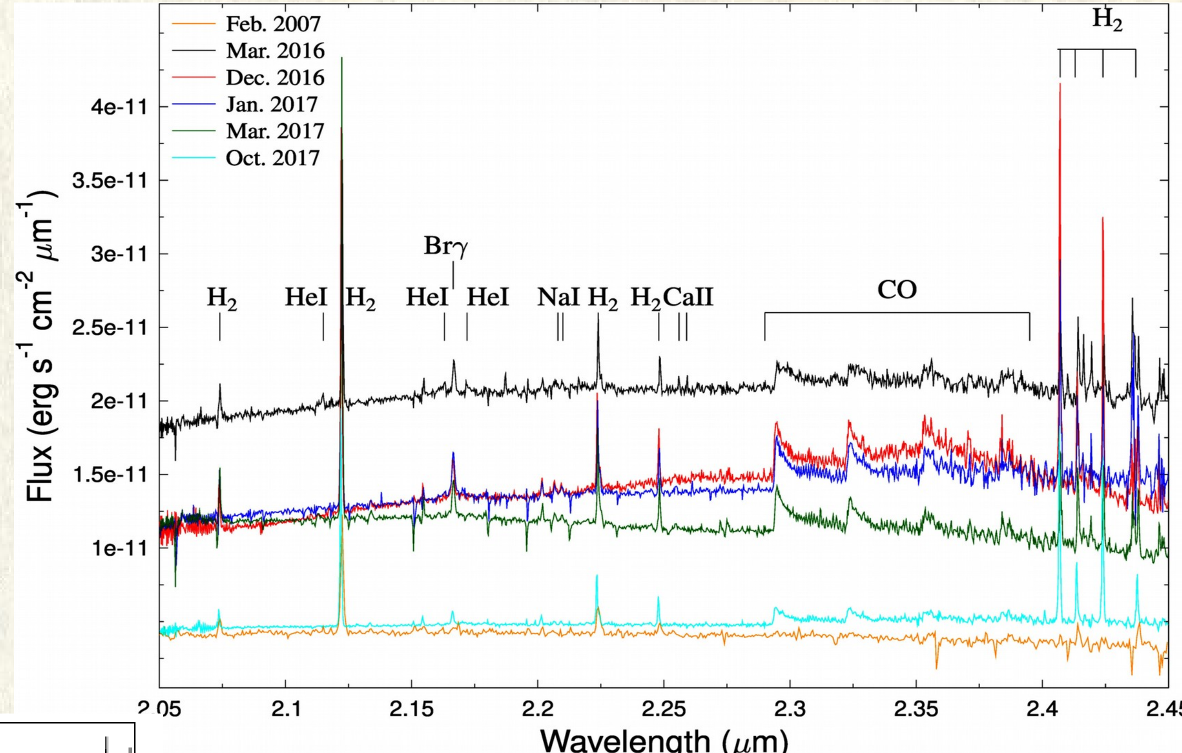
PANIC (Nov 2015)



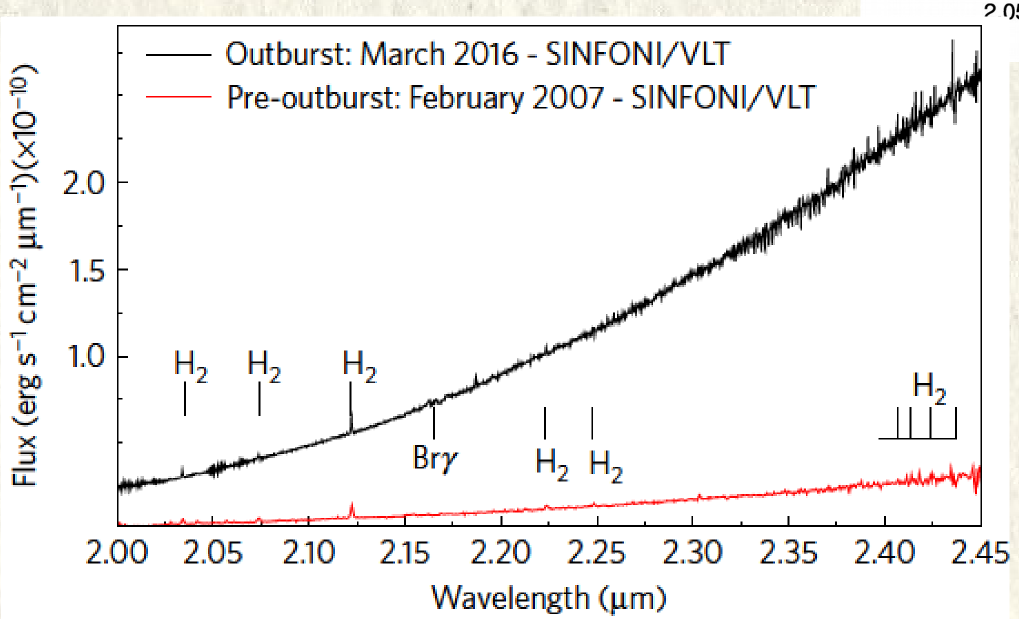
Stecklum+ (2016)

Spectroscopic Burst Verification

Caratti o Garatti+ (2017)

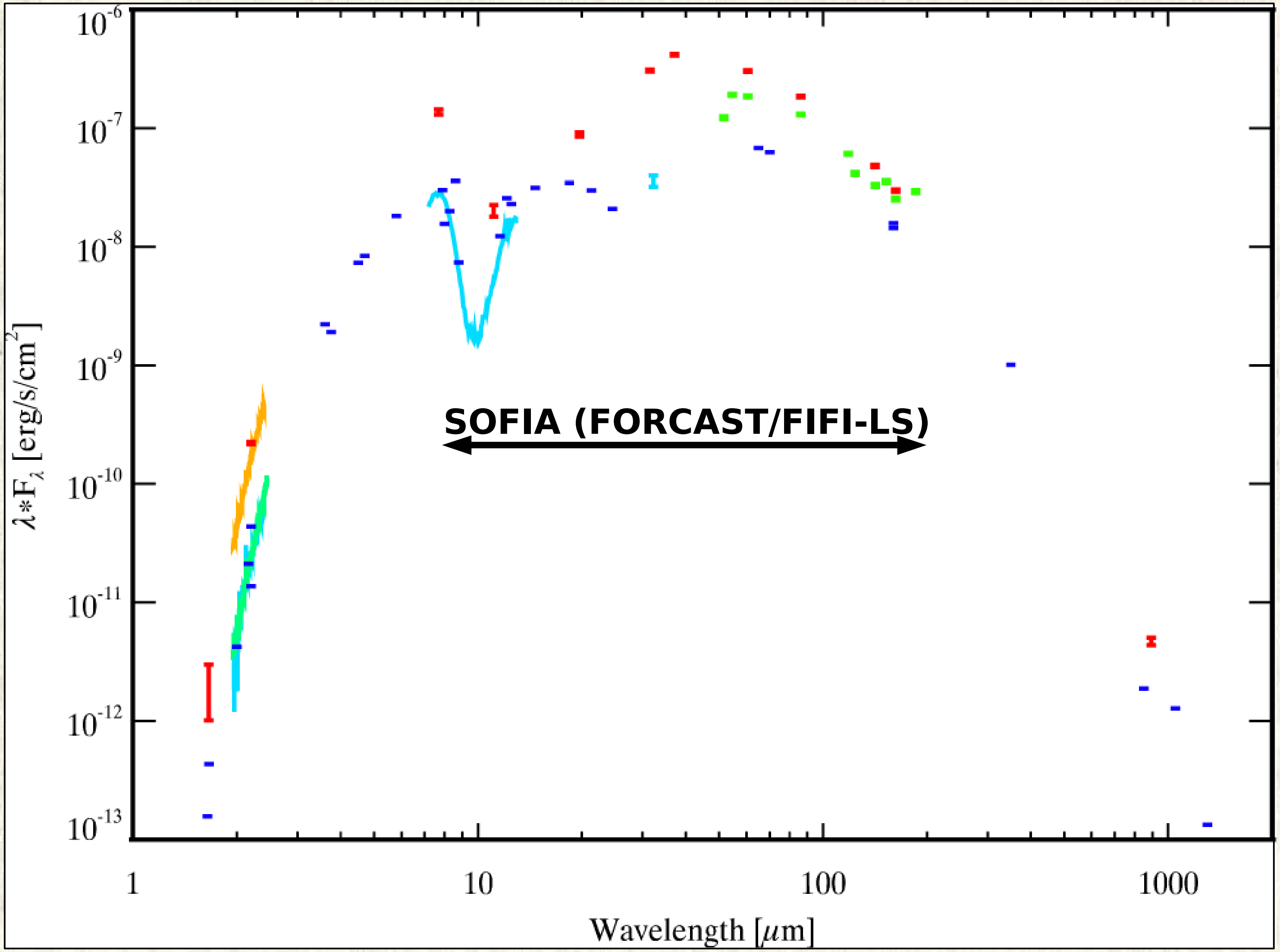


SINFONI on-source spectra showing an almost featureless red continuum before (red) and during the burst (black). Its spectral slope stayed constant.



Scattered-light spectra showing disk spectral features before (yellow) and during the burst (top down). The rise and fall of the continuum is obvious. The CO bandhead is weak during the burst peak but gets stronger afterwards, in accordance with recent work (Ilee+ 2018). The bandhead profiles vary during the disk cooling. In the NIR NIRS3 is almost back to the pre-burst state.

Evolution of the SED & Burst Quantities



Pre-burst, **burst** (spring 2016) and **after-burst** (spring 2017) SEDs of S255IR-NIRS3 (light lines are spectra)

Quantities from **burst** SED

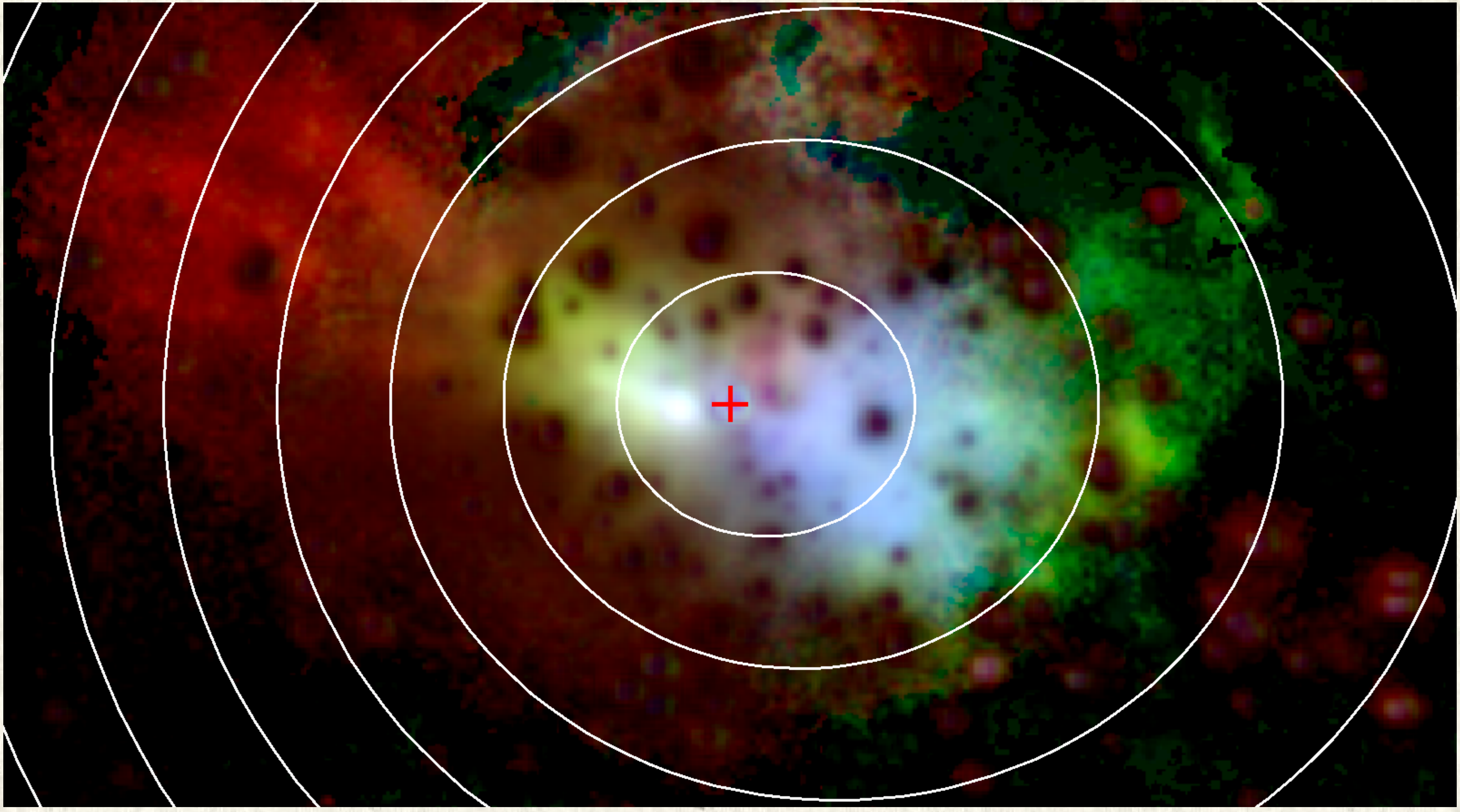
$L_{burst} \sim 1.6 \pm 0.4 \times 10^5 \, L_\odot$

$\dot{M}_{acc} \sim 5 \times 10^{-3} \, M_\odot/yr$

$M_{acc} \sim 2 \, M_{Jup}$

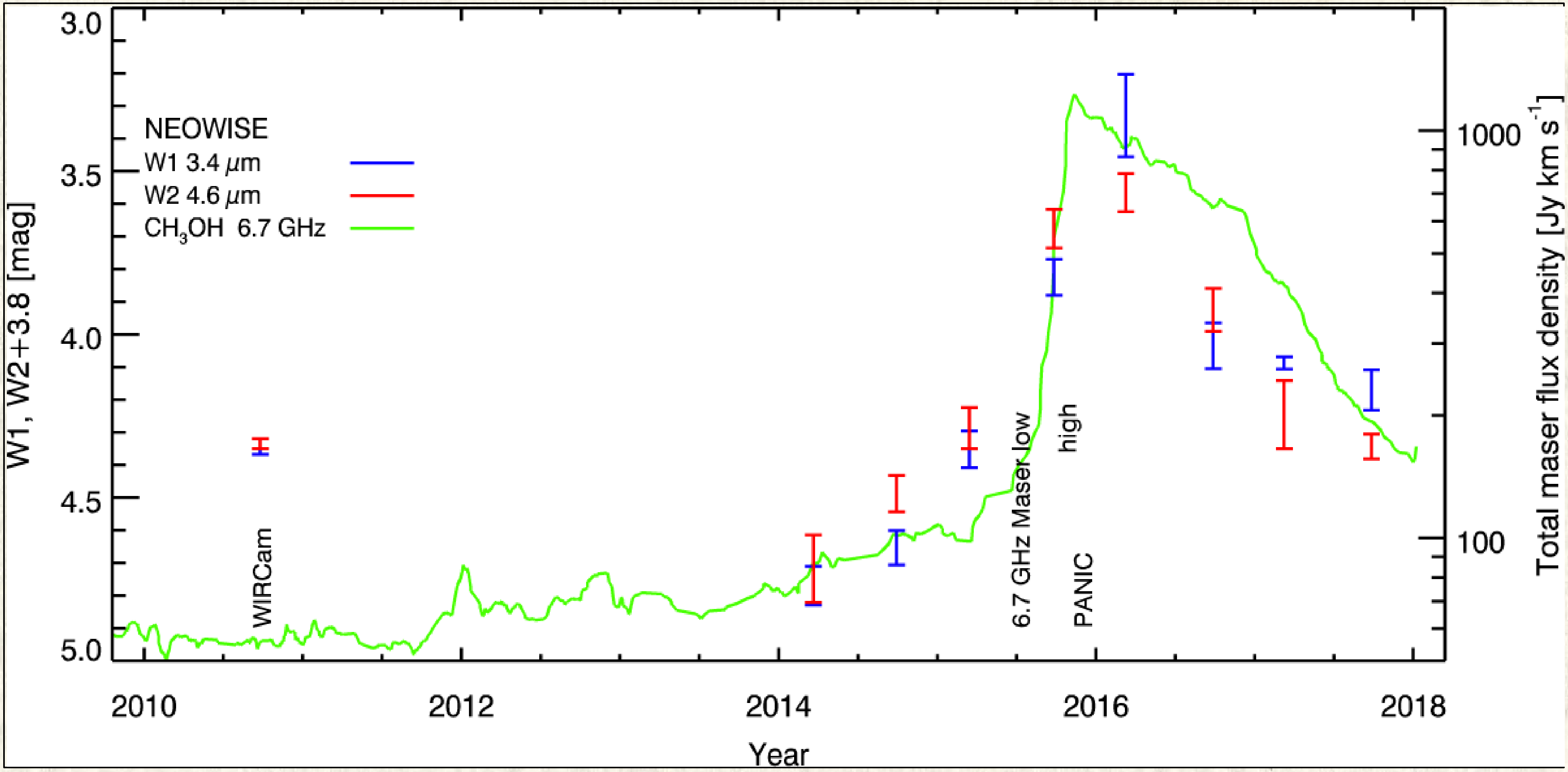
The burst from NIRS3 is the most luminous YSO out-burst ever. Caratti o Garatti+ (2017). It has been de-tected in the submm as well (Liu+ 2018).

Monitoring of the Light Echo - “Seeing” Time



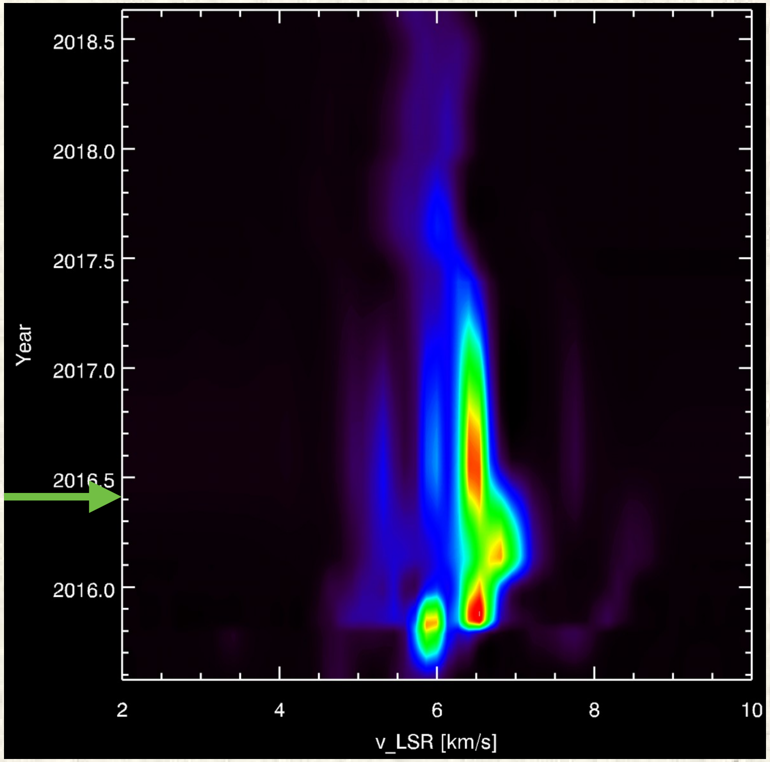
Light echo rendition based on “normalized” PANIC Ks images taken on 2015-11-28 (blue), 2016-03-03 (green) and 2016-11-20 (red). Ellipses indicate projected light-travel distances for multiples of 100 days for a flow inclination of 15°. The red cross marks the position of NIRS3. The white peak is due to a drop of the local optical depth between 2010 and 2015.

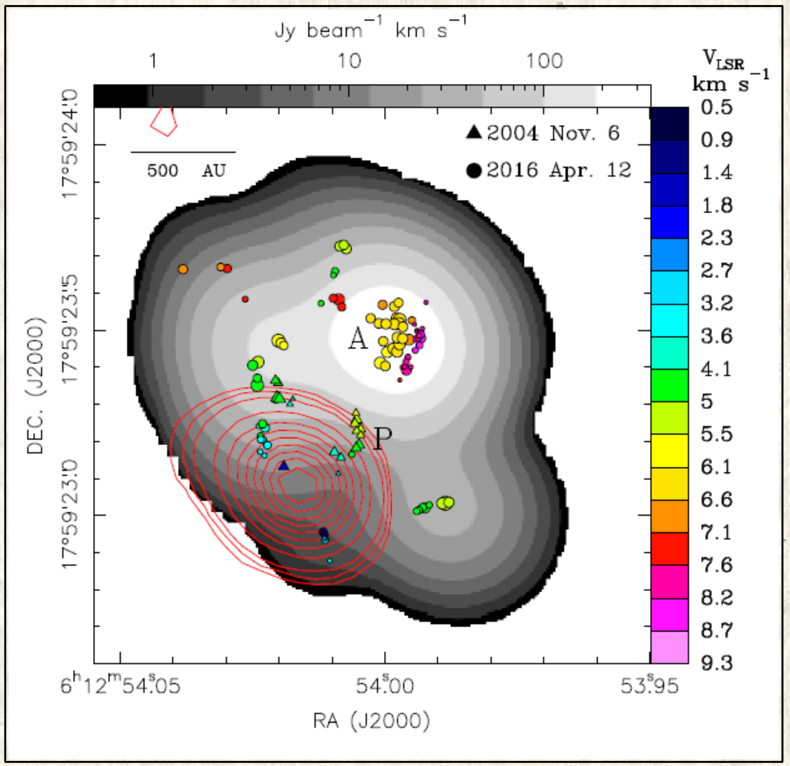
Precovery of the Burst in the NEOWISE Data



NEOWISE light curves (W2 mags shifted to match W1) which point to a burst beginning in early 2014 (Stecklum+ in prep.), in agreement with the total power maser light curve from Szymzcak+ (2018). The correlation between the IR and maser flux is evident.

Burst-induced Changes of the Maser Landscape





The dynamic maser spectrum shows that initially the dominating component at that time flared but was quenched later while new maser spots at different velocities were excited, situated further away from the MYSO. The green arrow marks the date of the maser mapping.

Map of the 6.7 GHz CH_3OH maser spots **before** (triangles) and **during** (circles) the outburst, respectively. The gray-scale image represents velocity-integrated emission. Red contours mark the 5 GHz radio continuum, centered at the NIRS3 position (Moscadelli+ 2017).

When Accretion turns into Ejection
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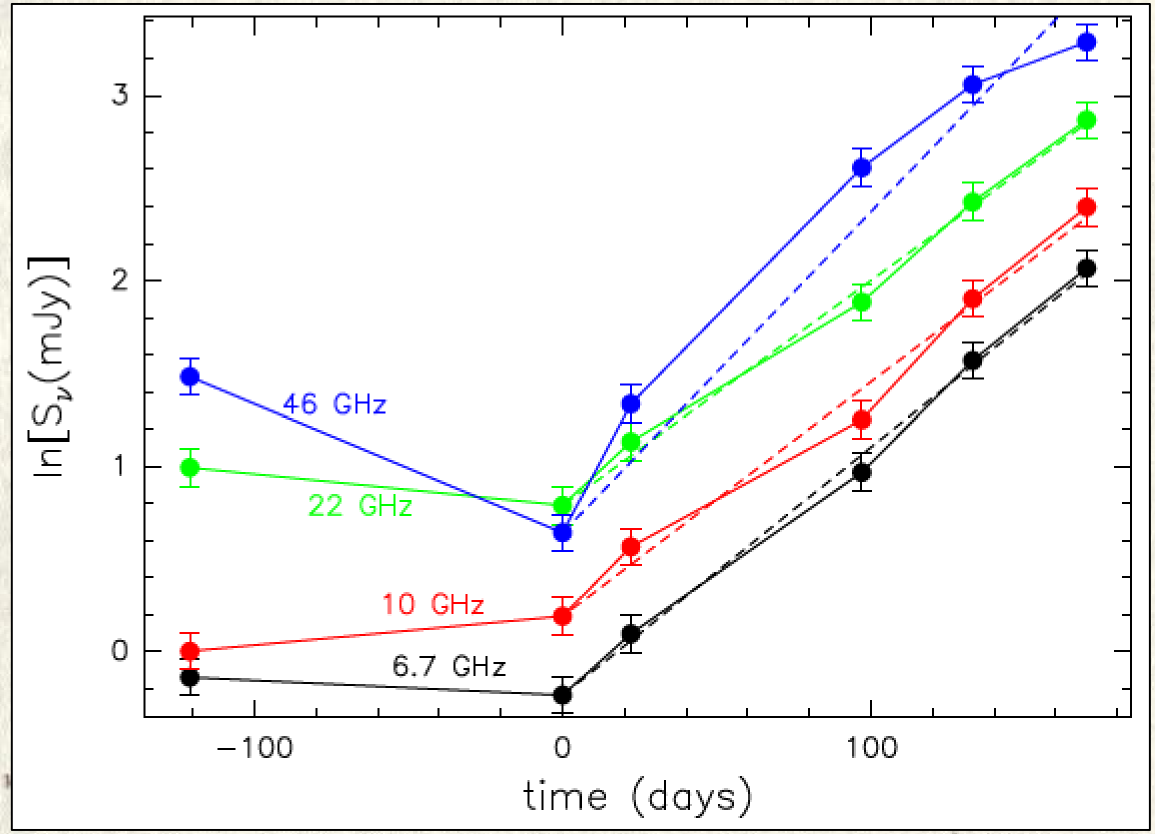
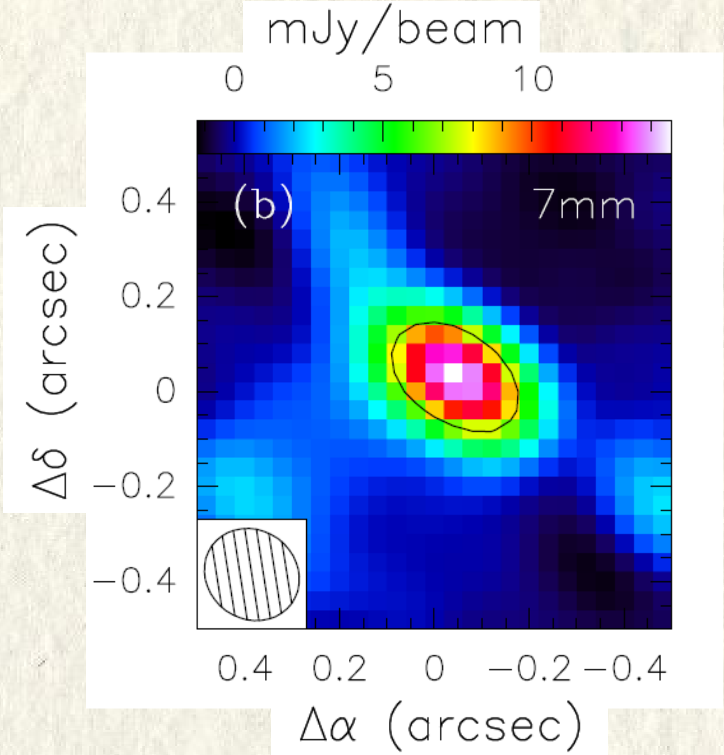
A New Episode of the Ionized Jet

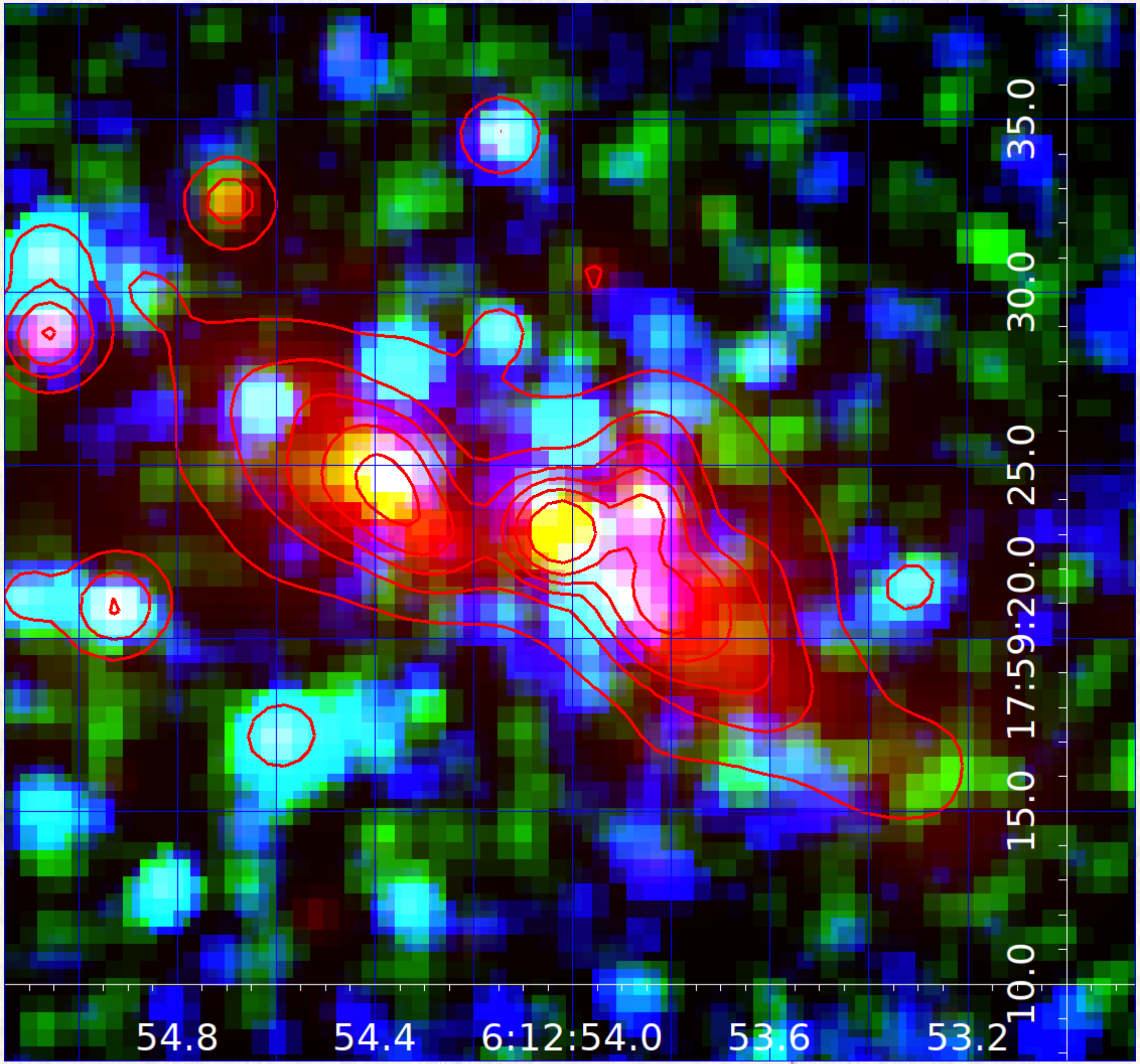


Rise of the radio continuum due to collisional ionization, t=0 corresponds to the 2nd epoch of our monitoring (2016-07-10). Dashed lines are fits using an exp(t) dependence (Cesaroni+ 2018).



Map of the 7mm continuum emission towards NIRS3, obtained on 2018-01-15. Comparison with the HPBW (bottom left corner) indicates that the source is barely resolved and elongated in the direction of the large scale radio jet.

X-ray Detection of NIRS3



Composite image based on archival Chandra frames from 2009 (blue, Mucciarelli+ 2011) and 2017 (green, PI D. Pooley) along with a PANIC Ks frame (red + contours). NIRS3 at the center appears yellow due to absence of any X-ray photons in 2009. Since the major accretion phase had passed in 2017 the X-ray emission likely originates from wind shocks rather than the accretion column.

Conclusions

- The NIRS3 burst reveals for the first time the full diversity of accretion burst-induced phenomena, triggered by the increase of the high luminosity. It confirmed the accretion-ejection connection.
- The NIRS3, NGC6334I-MM1 (Hunter+ 2017) and V723 Carinae (Tapia+ 2015) bursts confirm the presence of circumstellar disks around HMYSOs and strengthen evidence for high-mass star formation via disk accretion.
- They prove that erratic accretion due to disk instabilities occurs in circumstellar disks of HMYSOs in accordance with recent modeling (Meyer+ 2017, 2018 subm.).
- The transient disk/envelope heating has severe consequences for disk physics/chemistry, e.g. Vorobyov+ (2013).
- The burst-induced flares of Class II methanol masers confirm their excitation via IR pumping.
- These results indicate that star formation is more dynamic than previously thought, and follows the same principles across the stellar mass spectrum.