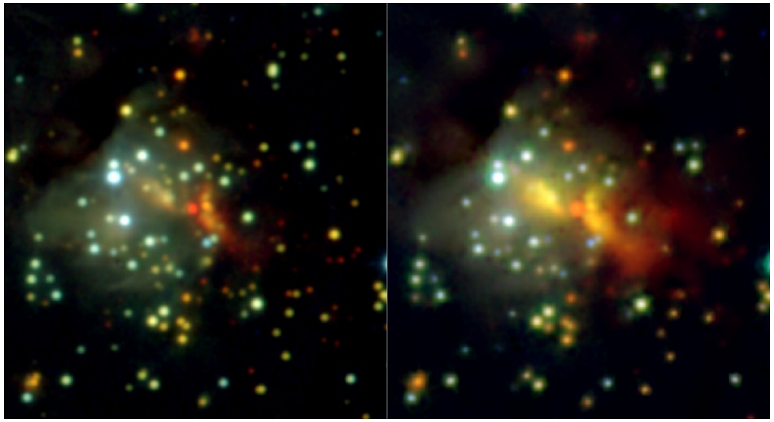
Reviewing recent observations of accretion bursts in high-mass YSOs



Alessio Caratti o Garatti

&

Jochen Eislöffel

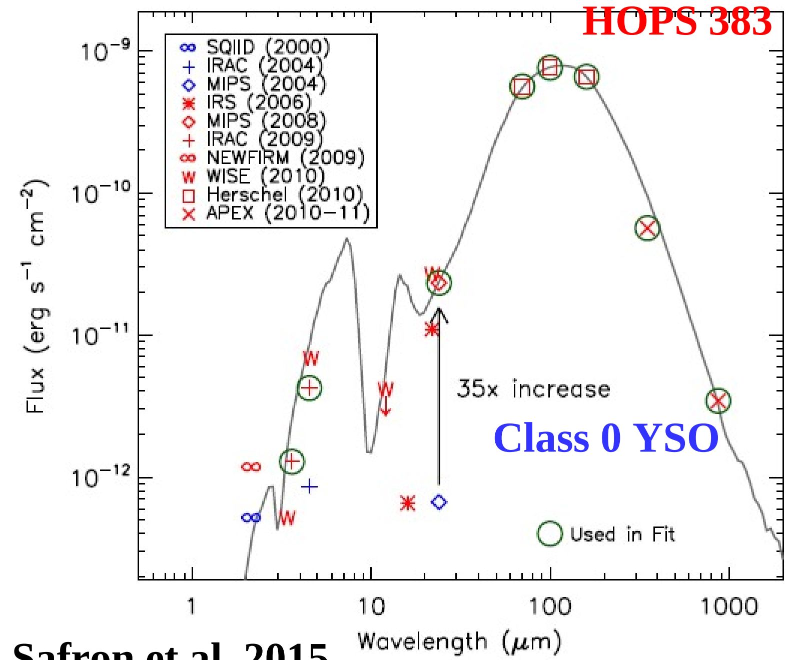
B. Stecklum, R. Cesaroni, L. Moscadelli, R. Burns, C. Brogan, T. Hunter, H. Linz, V. Wolf, G. MacLeod, the M2O team and many others…...

A common phenomenon across mass and time

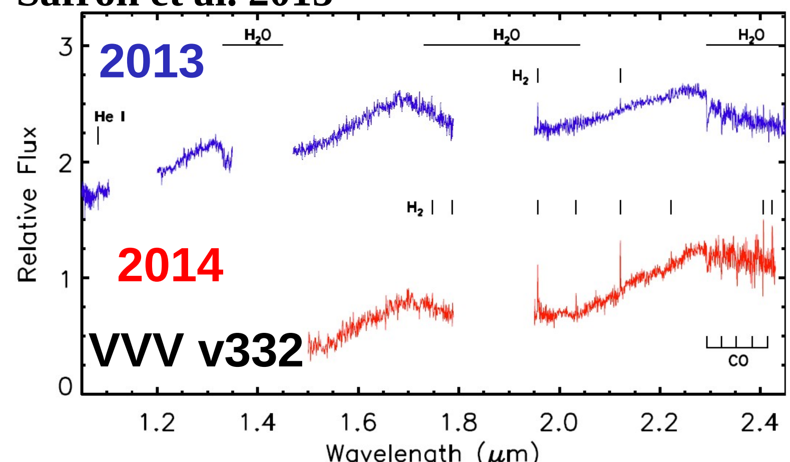
Accretion in YSOs not steady but episodic

Observed in:

- Low-mass protostars **(Safron+2015)** and pre-main sequence.
- Intermediate mass and Vellos **(Teixeira+2018, Hsieh+2018)**.
- High-mass YSOs (4 so far since 2016).
- FUors/EXors types are just two extremes of a broader continuum of events not well understood.
- How relevant is episodic accretion in star formation?



Safron et al. 2015

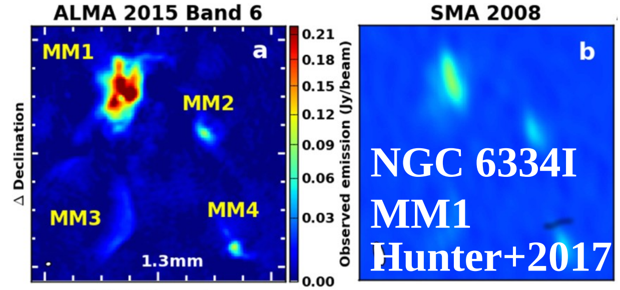


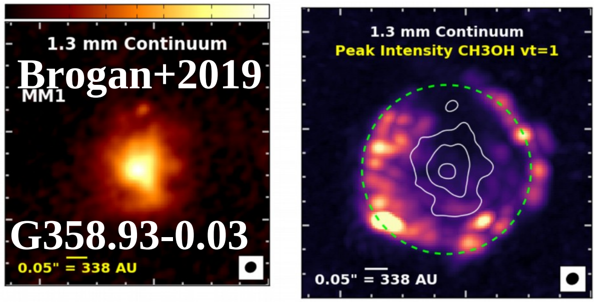
Contreras Peña et al. 2017

Accretion bursts in HMYSOs

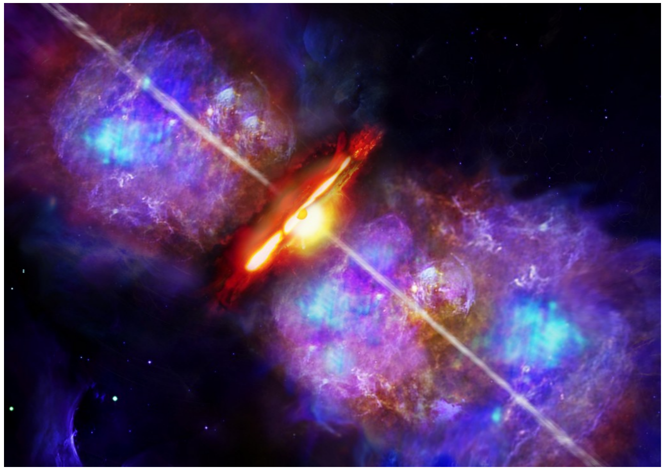
The discovery of episodic accretion in HMYSOs has opened a new research field in star formation.

- 4 accretion bursts detected and studied so far:
- S255IR NIRS 3: ~20 $M_\odot$ **(Caratti o Garatti+2017; Moscadelli +2017; Szymczak+2017; Liu+2018; Cesaroni+2018; Uchiama+2019)**
- NGC 6334I MM1: ~20 $M_\odot$ **(Hunter+2017,2018; Brogan+2018; McLeod+2018)**
- G358.93-0.03 MM1: ~10 $M_\odot$ **(Brogan+2019; MacLeod+2019; Breen+2019; Burns+2020; Stecklum+submitted)**
- G323.46-0.08: ~8 $M_\odot$ **(Proven-Adzri+2019; Wolf+ in prep)**





Main characteristics of HMYSO bursts



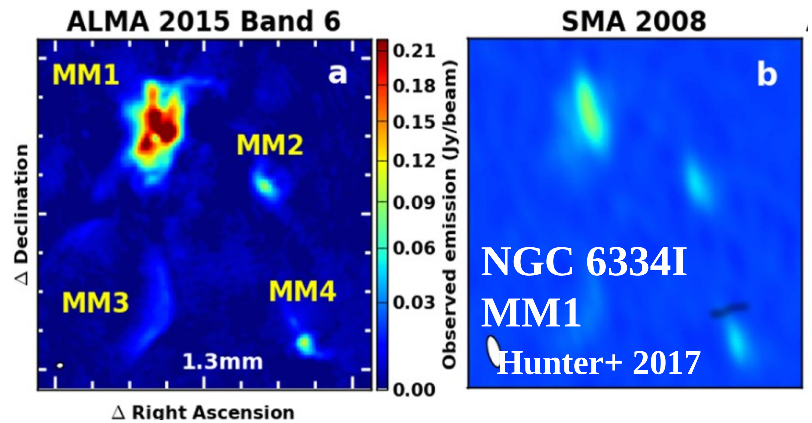
Despite the small sample large variety of physical properties as in low-mass bursts

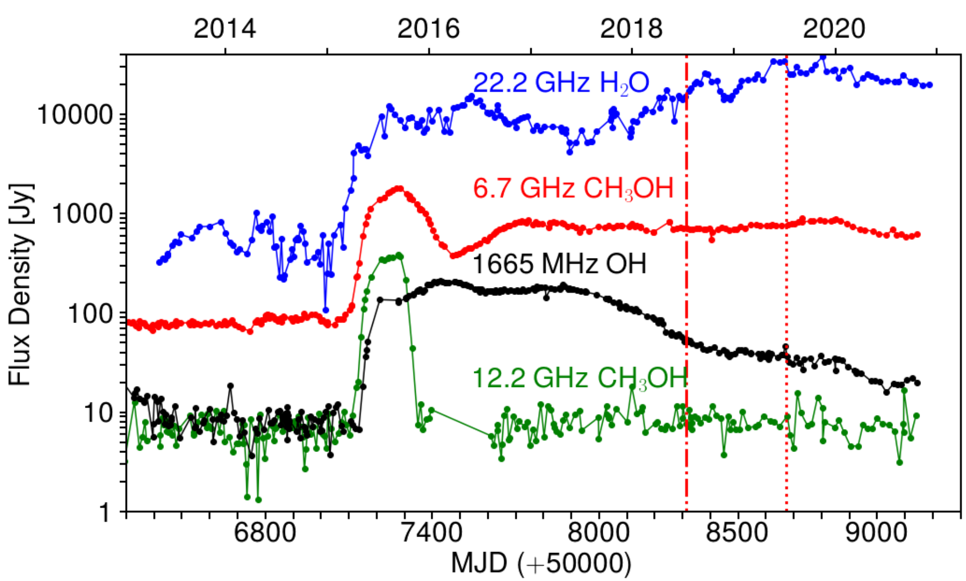
- Rising time: from 3 months to 1 year
- Length: from 7 months to 6 years (1 still active after 6 yrs)
- Increase in L_{bol} (ΔL_{acc}): from 6 to 70 times (from few 10^3 to few 10^5 $L_\odot$)
- Accretion rates in burst: up to several 10^{-3} $M_\odot$/yr
- Released energy: from few 10^{45} to several 10^{46} erg
- All bursts signalled by methanol maser flares

Maser Monitoring Organization

NGC 6334I MM1 – a FUor-like burst?

- N6334I-MM1 most embedded source, burst detected in the mm, H_2O, CH_3OH, OH maser flares **(Hunter+ 2017, MacLeod+2018)**
- Flared mid-IR to submillimeter
- L_{bol} increased by 70x (to 10^5 $L_{\odot}$)
- Released energy (10^{46} erg)
- Burst still active after 6 years (FUor-like counterpart?)





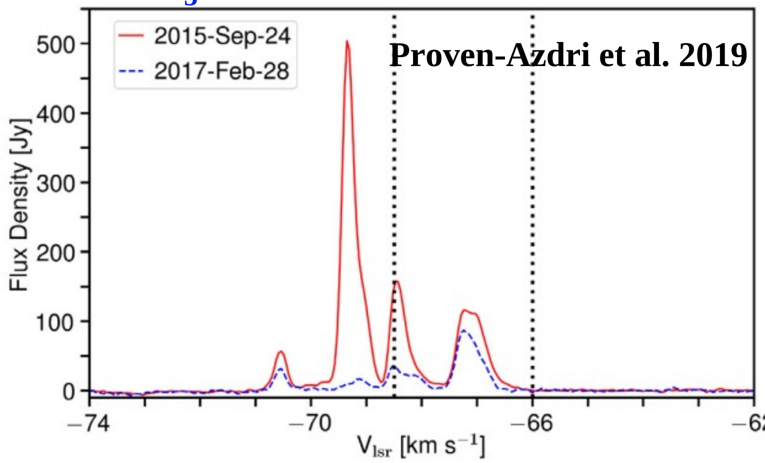
MacLeod et al. in prep.

G323.46-0.08 – an archival burst

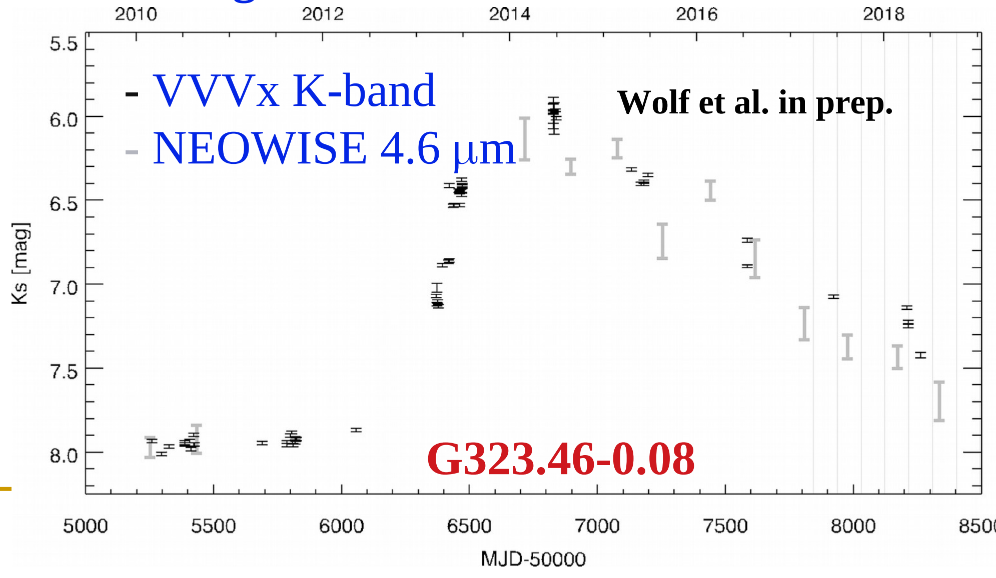
Burst discovered in 2018 from archival data

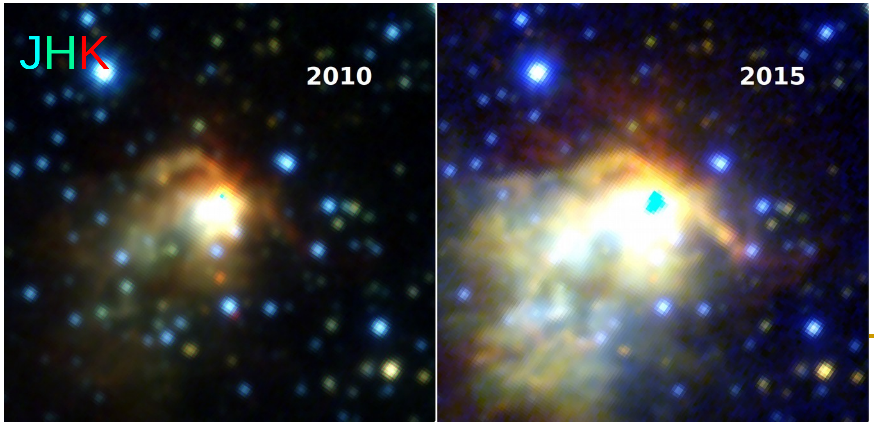
- Poorly known HMYSO ($M \sim 8M_{\odot}$?) with an UCHII region
- CH3OH maser flare
- From VVV and WISE NIR light-curves the burst lasted 4-5 years

CH_3OH **maser flare @6.7 GHz**



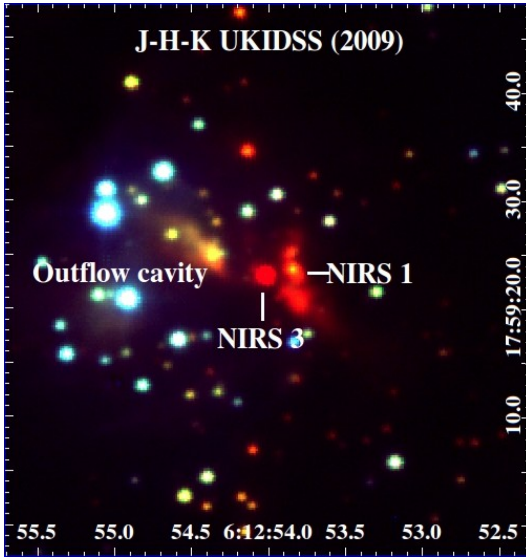
NIR light-curves



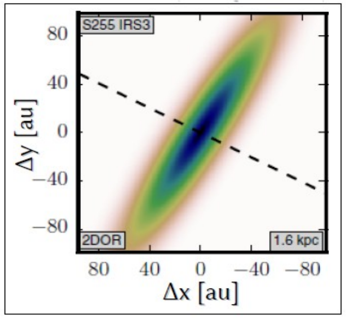


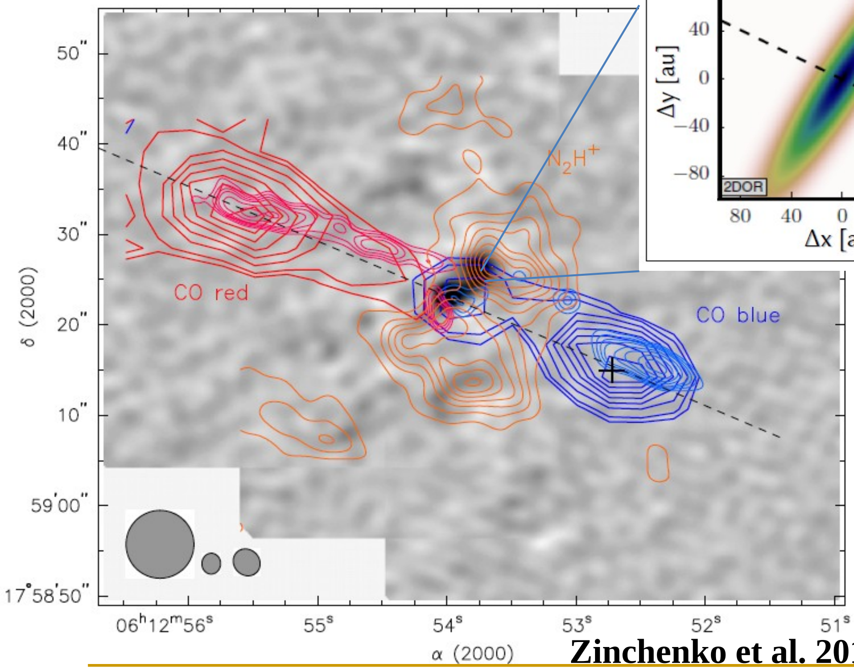
Introducing the HMYSO S255IR-NIRS3

- L_{bol}= 2x10^4 $L_\odot$; M_*~20 $M_\odot$; d=1.8±0.1 kpc (**Burns+ 2016**)
- Disk, jet and outflow
- H_2O (**Goddi+ 2007**) & CH_3OH (**Menten 1991**) masers



Boley et al. 2011



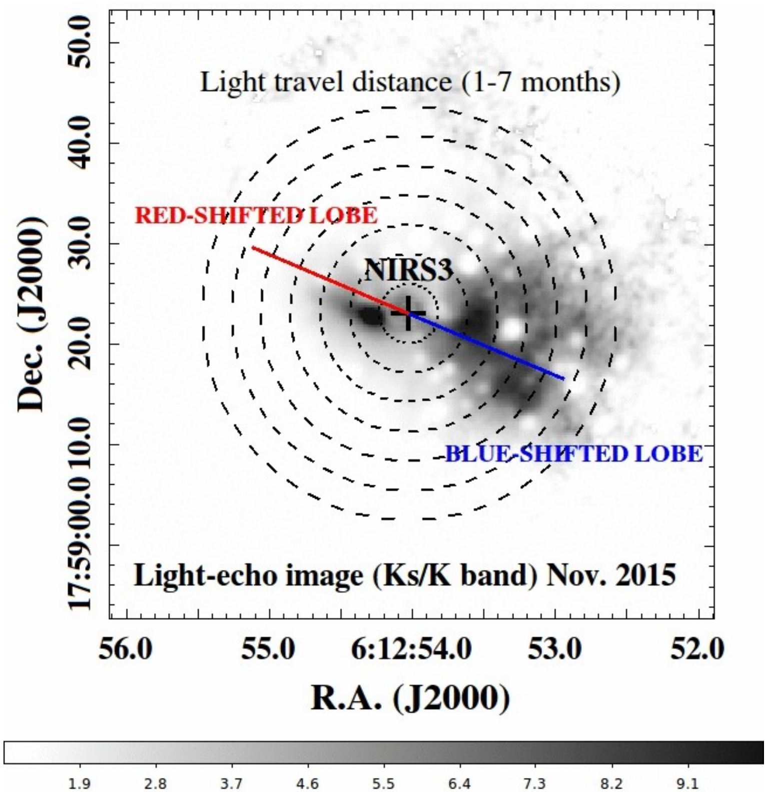


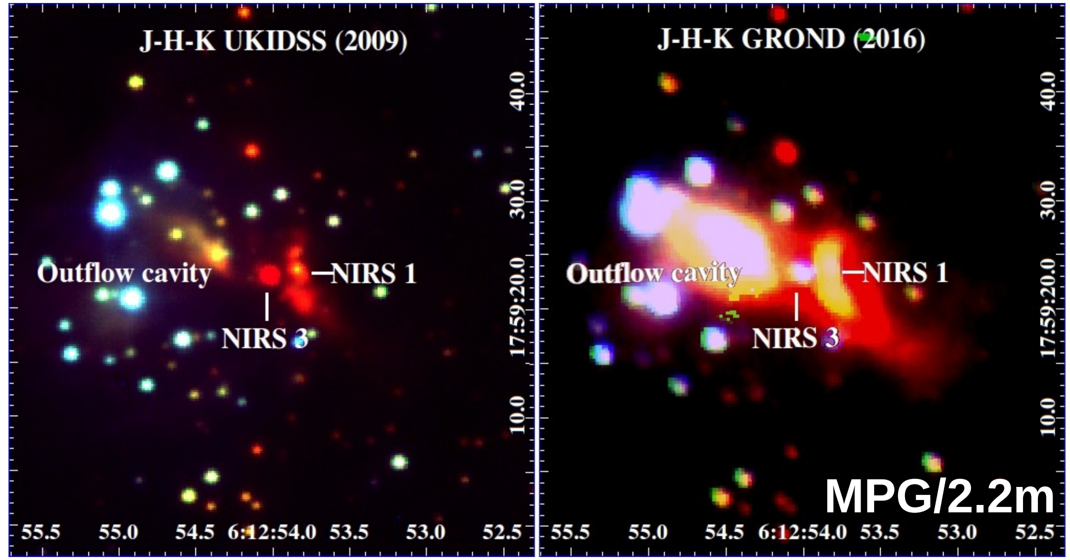
Zinchenko et al. 2015

- CH_3OH masers are pumped by IR radiation
- CH_3OH flare (**Fujisawa+ 2015**) triggered our observations....

First disk-mediated accretion burst in a HMYSO

- UKIDSS (Dec. 2009) vs. PANIC (Nov. 2015): ΔH=3.5 mag ΔK=2.5 mag



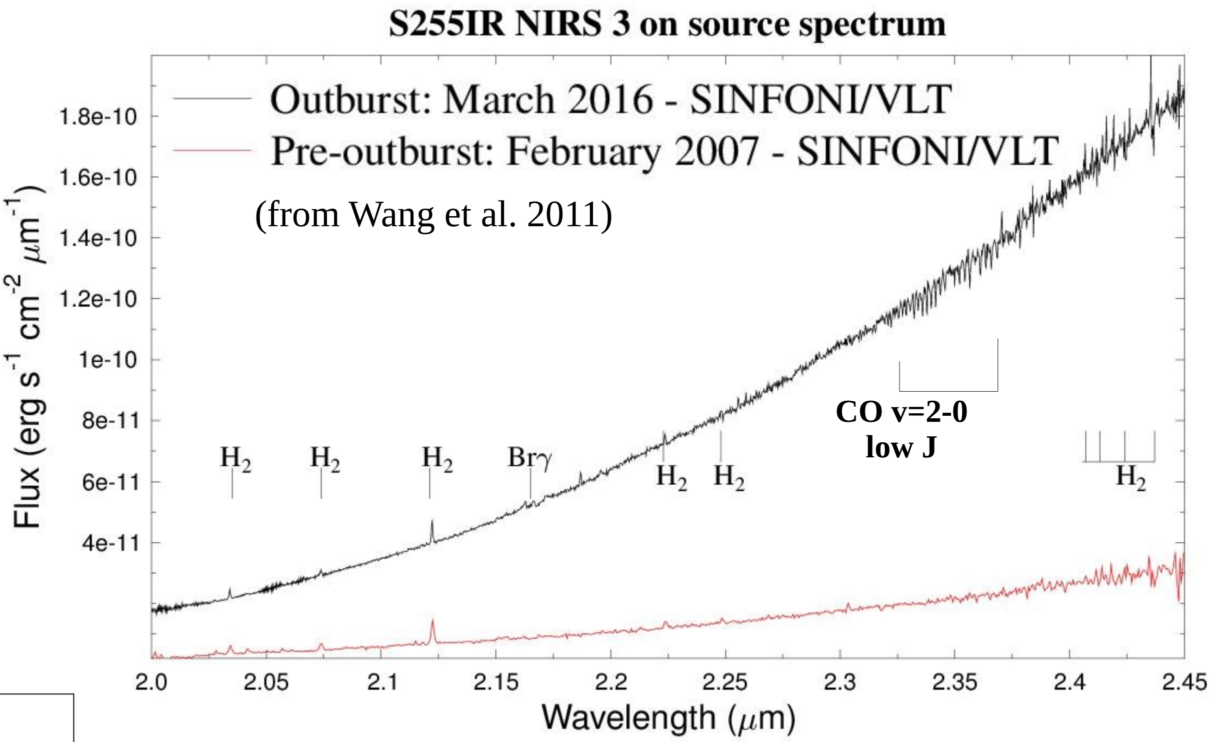


Caratti o Garatti et al. 2017, Nature Phys.

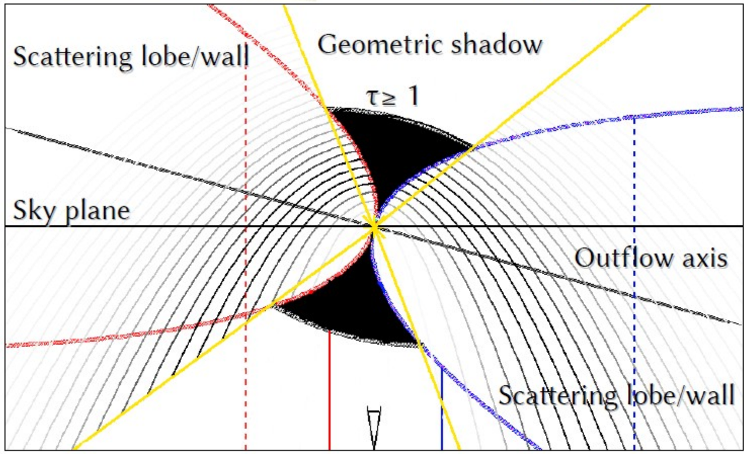
- Accretion burst → flash-light from outflow cavities.
- Light echo motion indicating outburst started before the maser flare (mid-June 2015 vs Sept. 2015)

On source NIR spectroscopy & photometry

On source spectroscopy almost featureless (H_2, Brγ, CO) with a rising continuum.

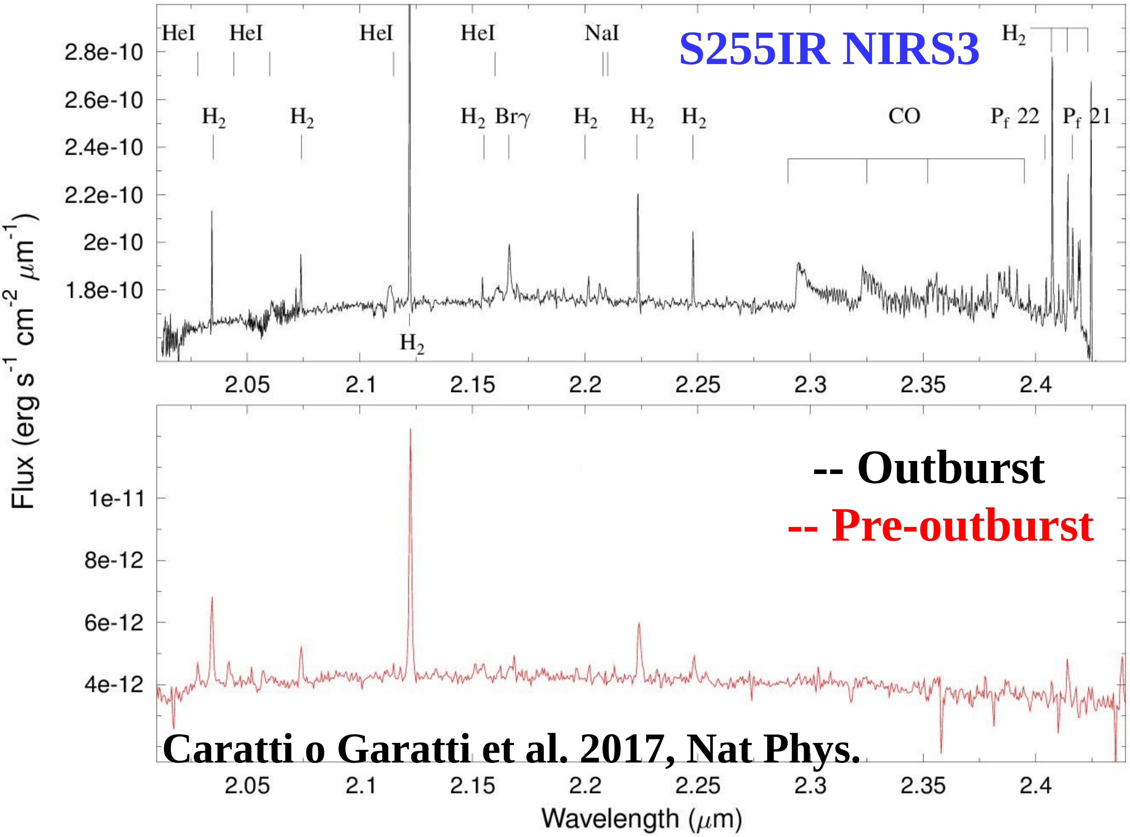


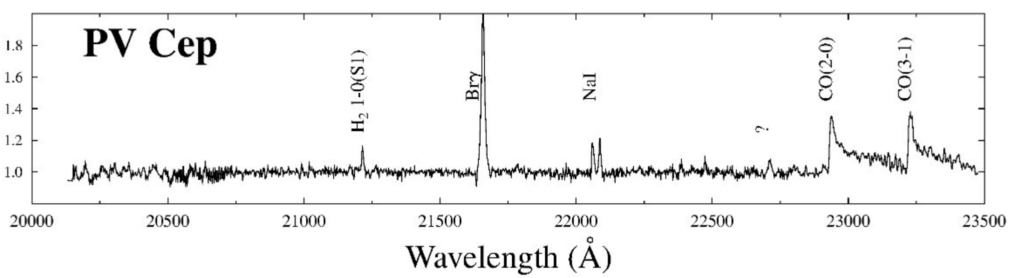
Caratti o Garatti et al. 2017, Nat. Phys.



Disk almost edge-on: need to look at the outflow cavities to see the accretion region/inner disk region

K-band spectrum of the outflow cavity





Caratti o Garatti et al. 2013

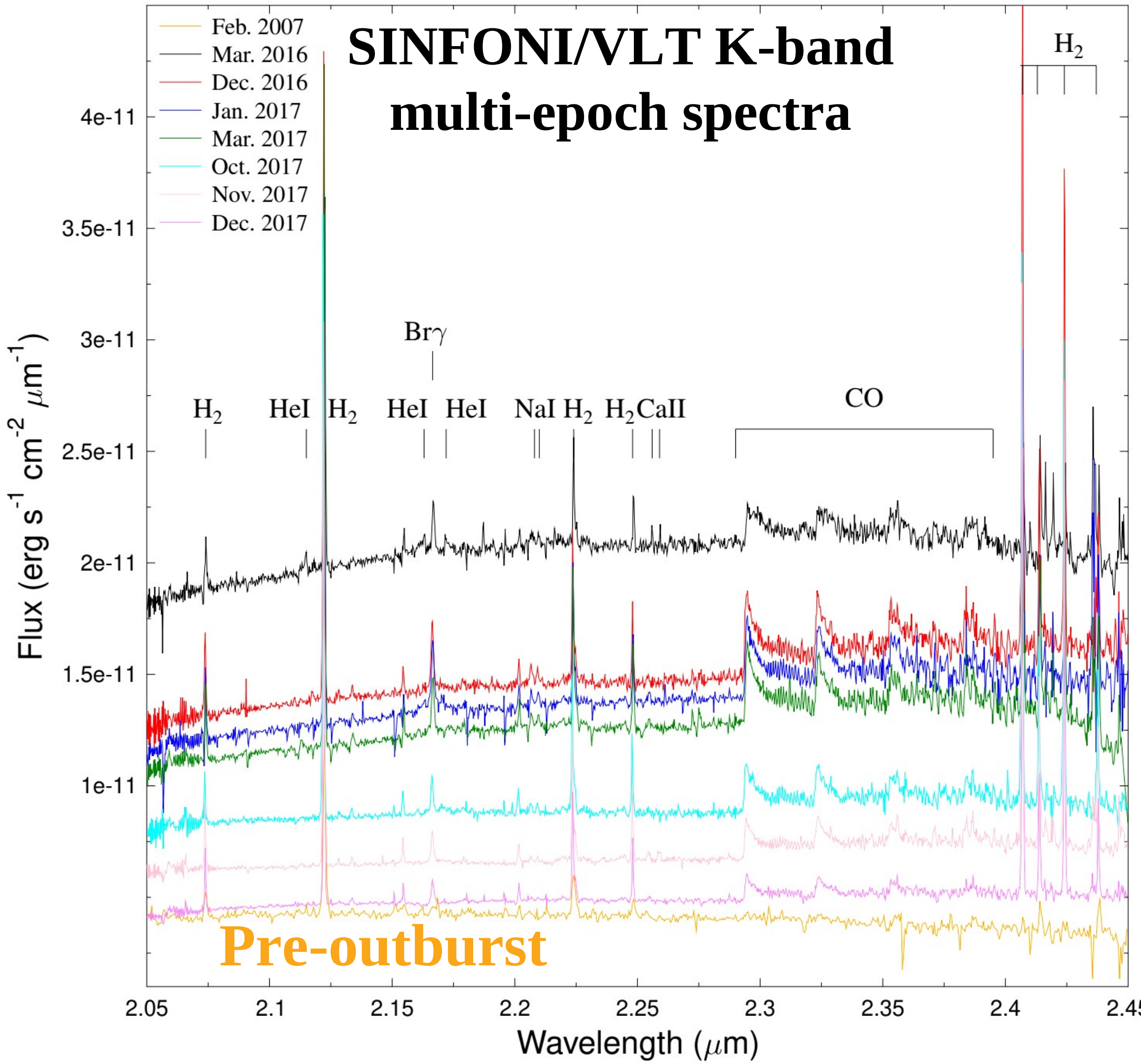
- CO & NaI lines → presence of a disk
- HI & HeI lines → increased accretion and wind activity
- H_2 emission from shocks
- Same lines as in EXors but 10^3-10^4 times more luminous.

K-band spectrum of a low-mass EXor outburst

Spectroscopic evolution of the burst in the NIR

- NIR continuum flux back to pre-outburst values (Dec. 2017) accretion burst is over.

- Line evolution: HI & HeI accretion/wind lines fading or disappeared; inner gaseous disk is cooling (CO band-heads); H_2 line intensities are increasing: jet activity



Caratti o Garatti et al. in prep.

SED and outburst parameters

- MIR + FIR photometric data from FORCAST & FIFI-LS

- Burst parameters:

$L_{bol} = (1.6\pm0.3)x10^5\ L_\odot$

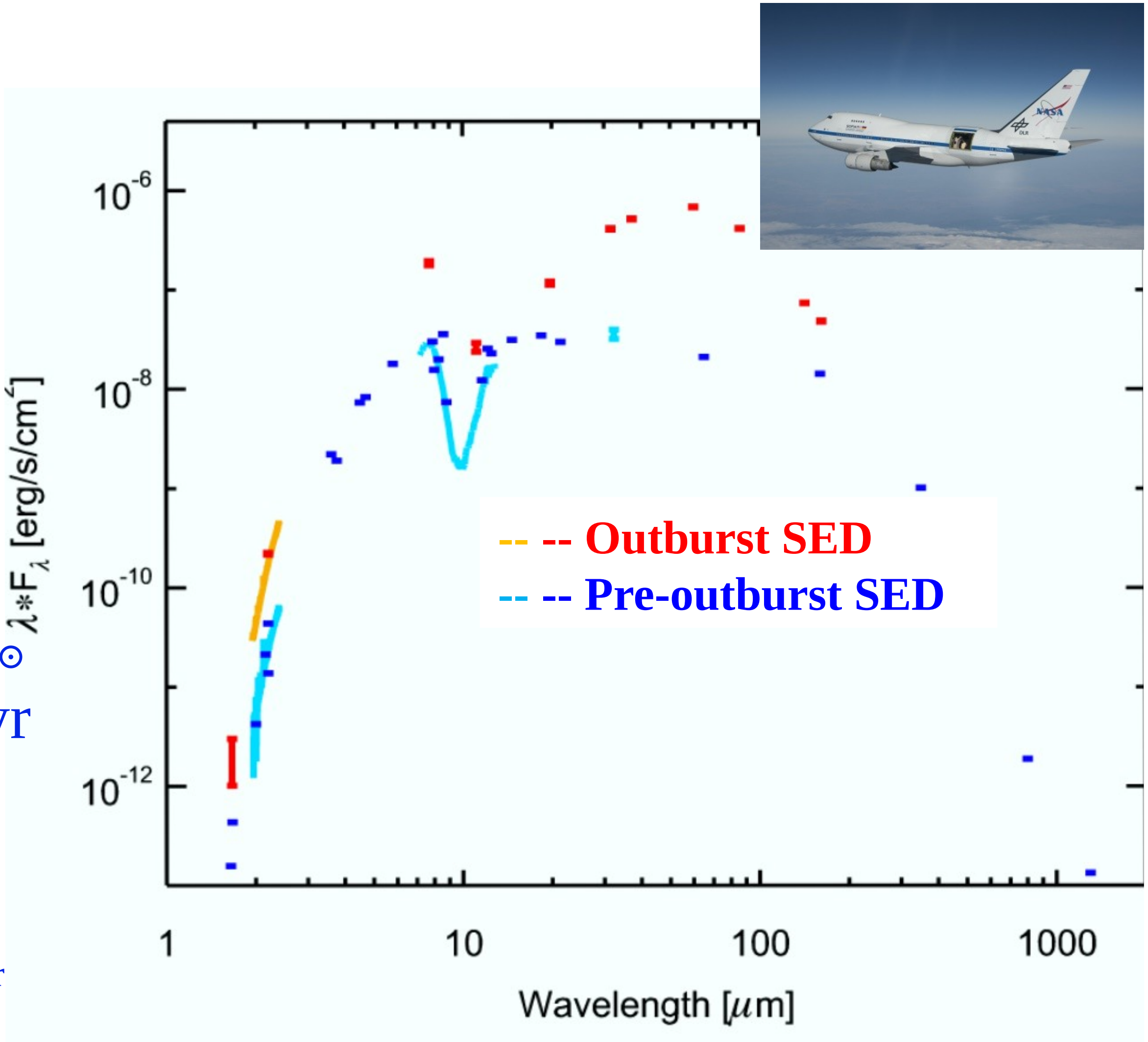
$\Delta L_{acc} = (1.3\pm0.4)x10^5\ L_\odot$

$\Delta \dot{M}_{acc} = (5\pm2)x10^{-3}\ M_\odot/yr$

(with $M_* = 20\ M_\odot$ & $R_* = 10\ R_\odot$)

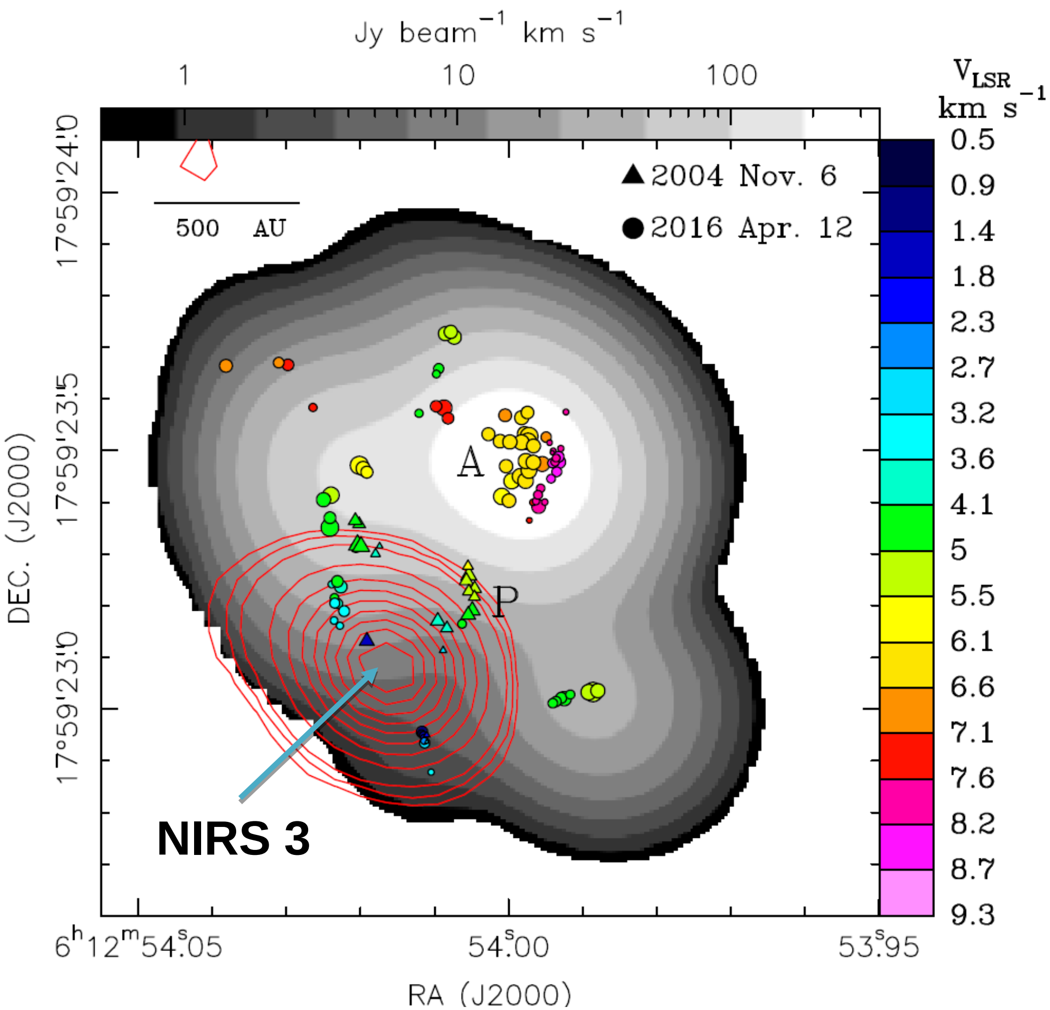
energy released ~ 10^{46} erg

accreted mass ~ 2 $M_{Jupiter}$



Caratti o Garatti et al. 2017, Nat Phys.

CH_3OH maser flare with VLBI



Moscadelli et al. 2017

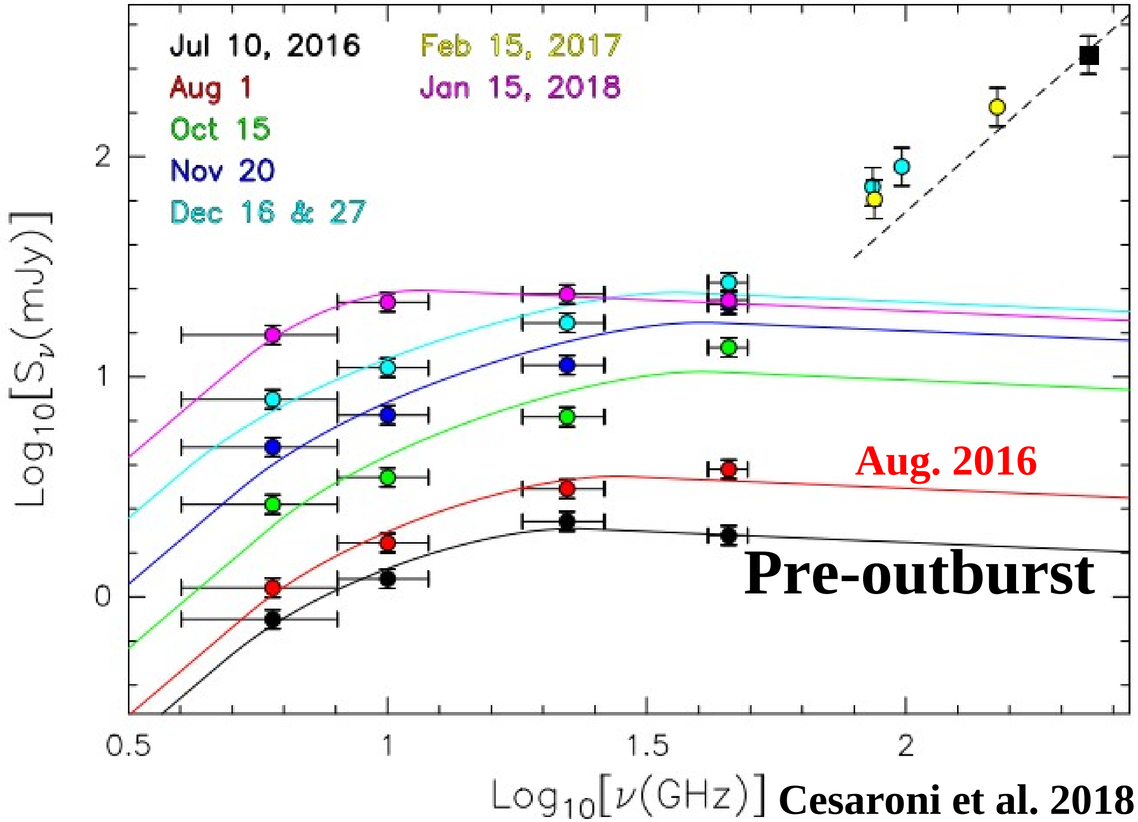
Environment of NIRS 3 strongly transformed by the accretion burst:

- CH_3OH emission (cluster P) close (~300 au) to source disappears, likely destroyed by UV radiation.
- New cluster of masers (cluster A) excited (at ~1500 au from source) produces the observed flare pumped by IR radiation

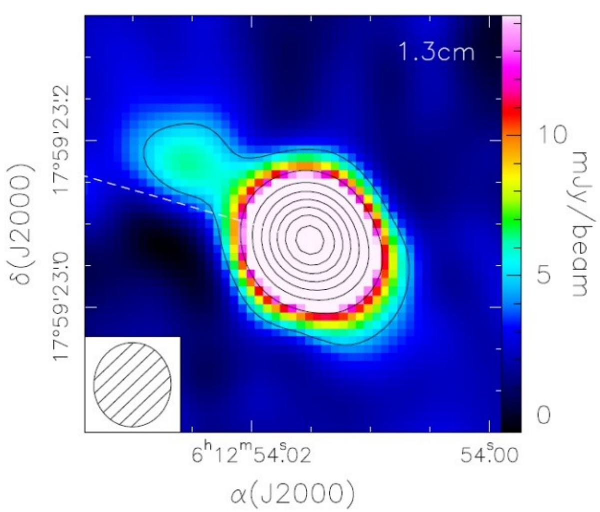
Radio jet burst: accretion turns into ejection

- Radio continuum flux increases from Aug. 2016 i.e. *~13 months after* beginning of accretion burst
- Wind re-collimation produces a radio jet.
- Spectral slope typical of a thermal jet.

JVLA multi-epoch spectrum of the jet



Cesaroni et al. 2018

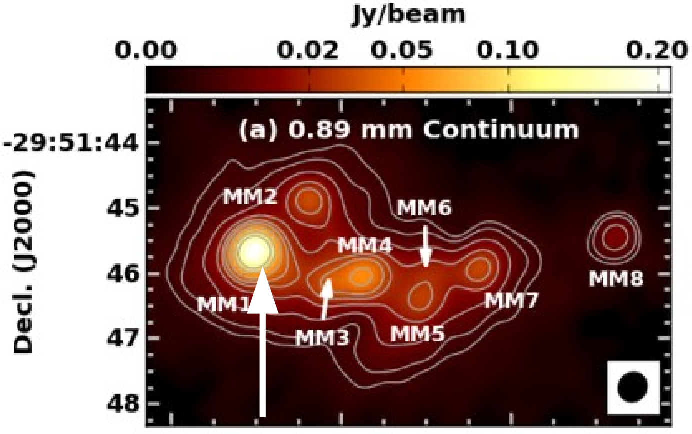


- A new knot has appeared - Dec. 2016

Accretion has turned into ejection!

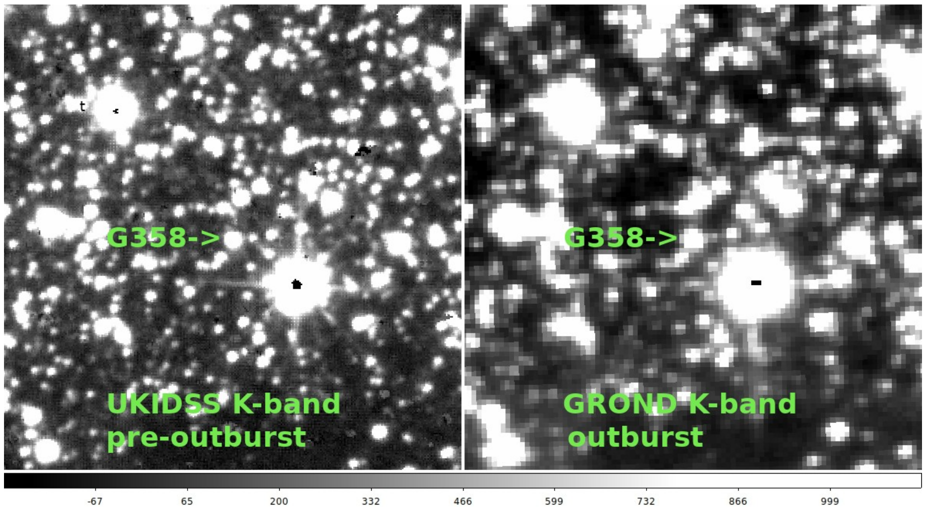
G358.93-0.03-MM1: another NIR dark burst

- 6.7 GHz CH_3OH burst in G358 **Sugiyama+2019**
- MM1 poorly studied HMYSO, ~5x10^3 $L_\odot$, ~10 $M_\odot$, at d ~ 6.7 kpc, located in a cluster
- Follow-up by M2O team: wealth of masering lines in H_2O, OH, CH_3OH flaring **Breen+2019; Brogan+2019; MacLeod+2019** and new maser species HDO, HNCO,13CH3OH discovered **Chen+2020a,b**

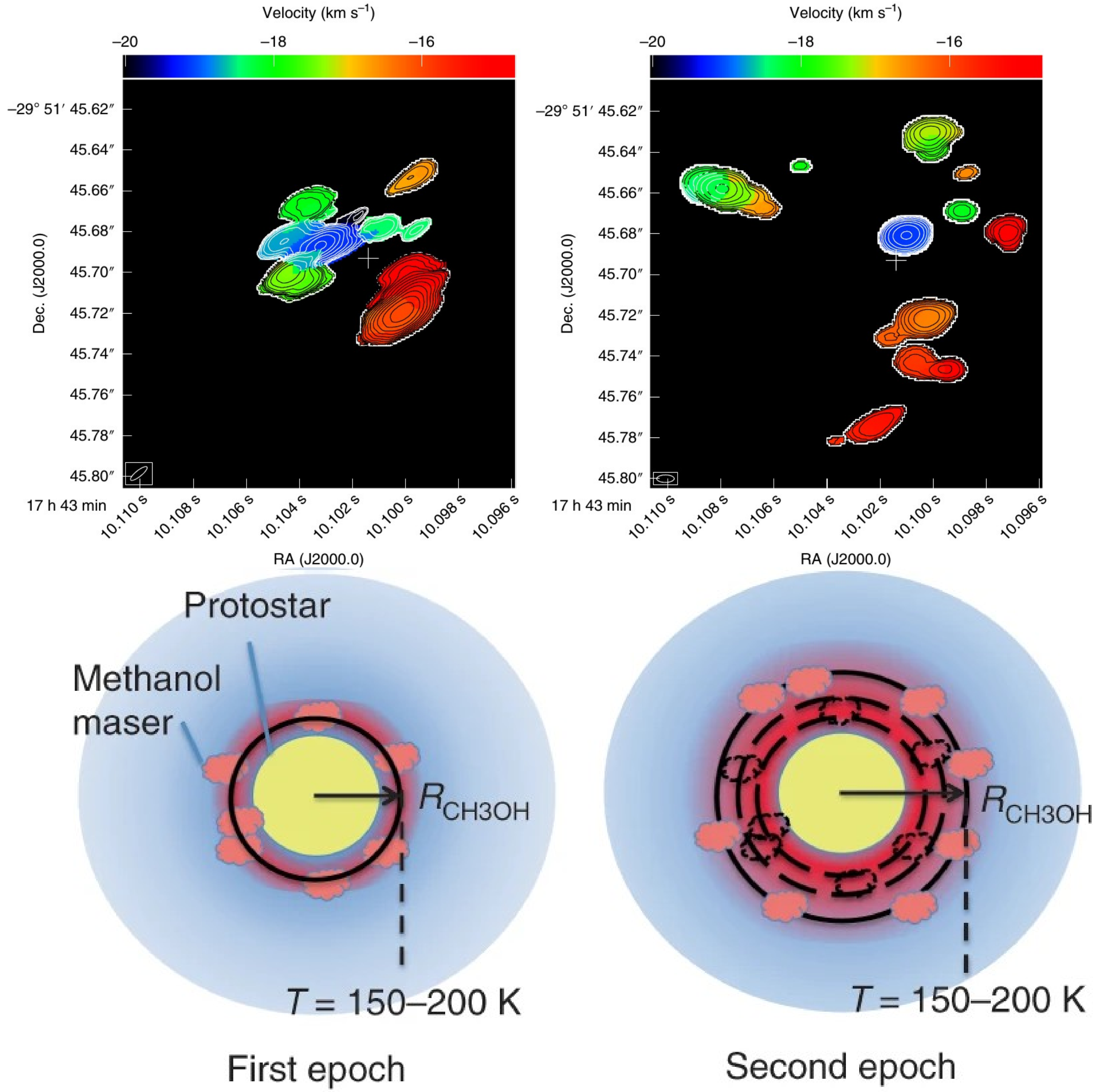


Brogan et al. 2019

- No detection of mm variability
- GROND @ 2.2-m MPG: no photometric variation in J,H,K of the alleged NIR counterpart: - NIR dark outburst!

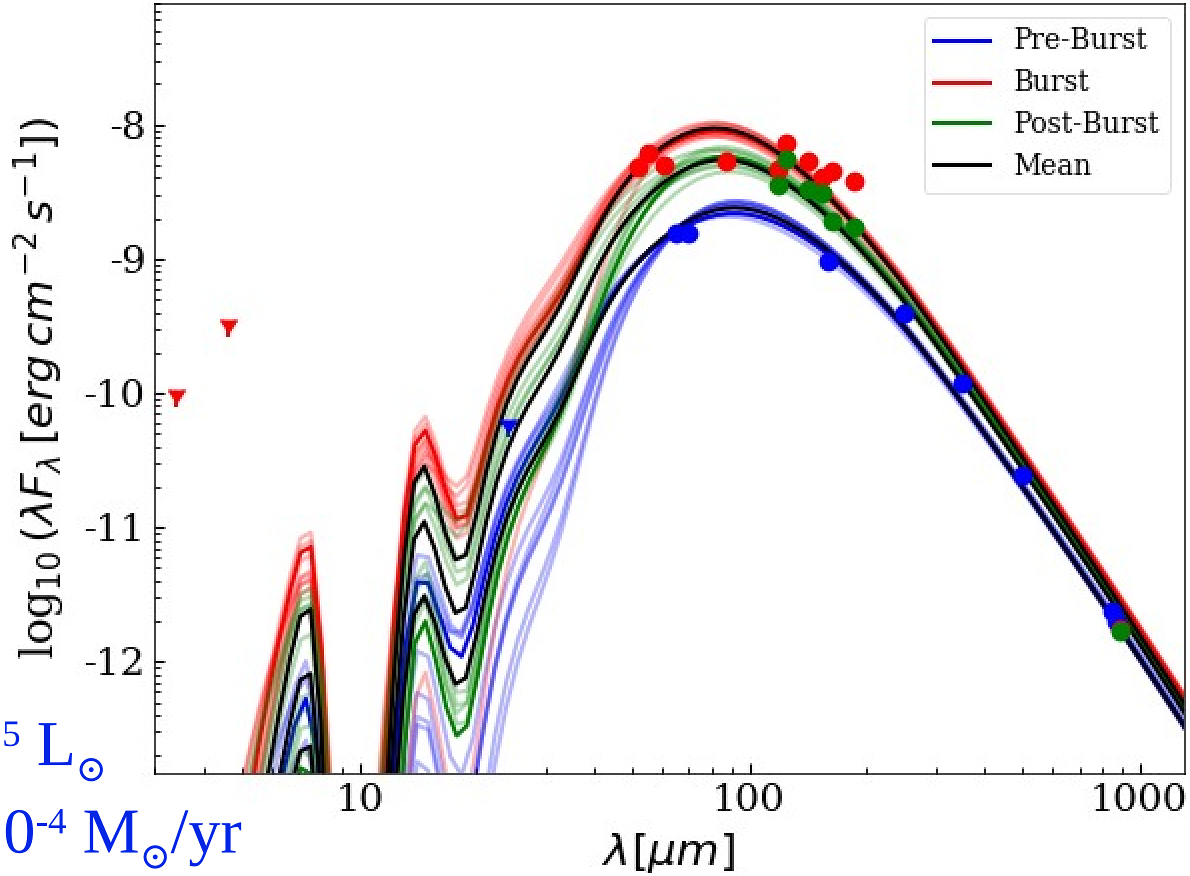


Evidence for propagation of heat wave induced by the accretion burst



Burns et al. Nat Ast. 2020

Confirmation of the accretion burst by SOFIA



Burst parameters:

ΔL_{acc} = (1.8±0.5)x10^5 $L_\odot$

ΔM_{acc}= (5.3±11/4)x10^{-4} $M_\odot$/yr

(with M_*=9.7 $M_\odot$ & R_*=3.9 $R_\odot$)

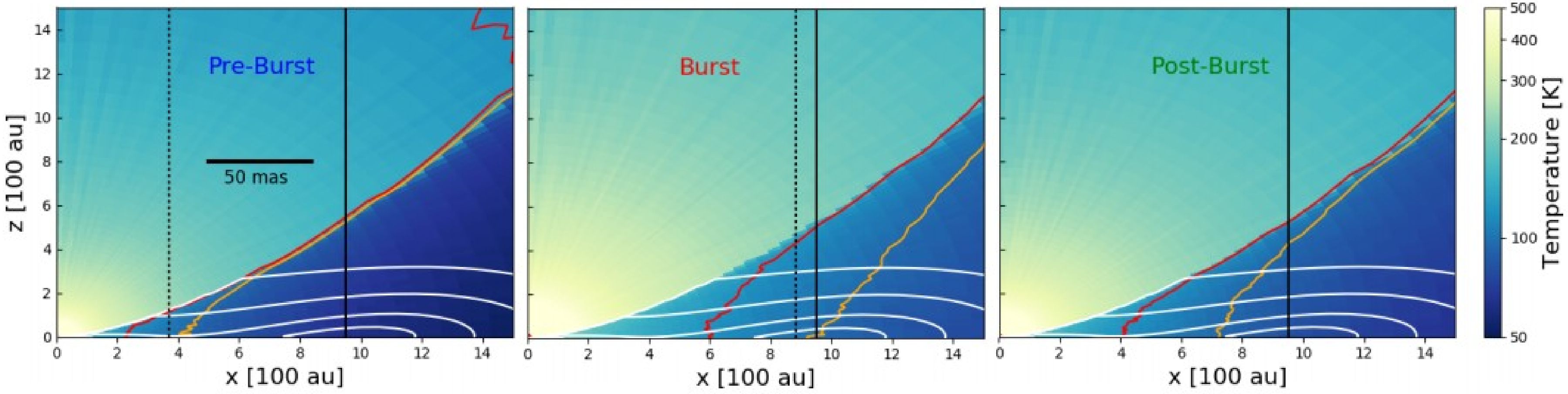
accreted mass ~ 180 M_{Earth}

Stecklum et al. submitted

Methanol maser relocation

Methanol maser ring

disk edge



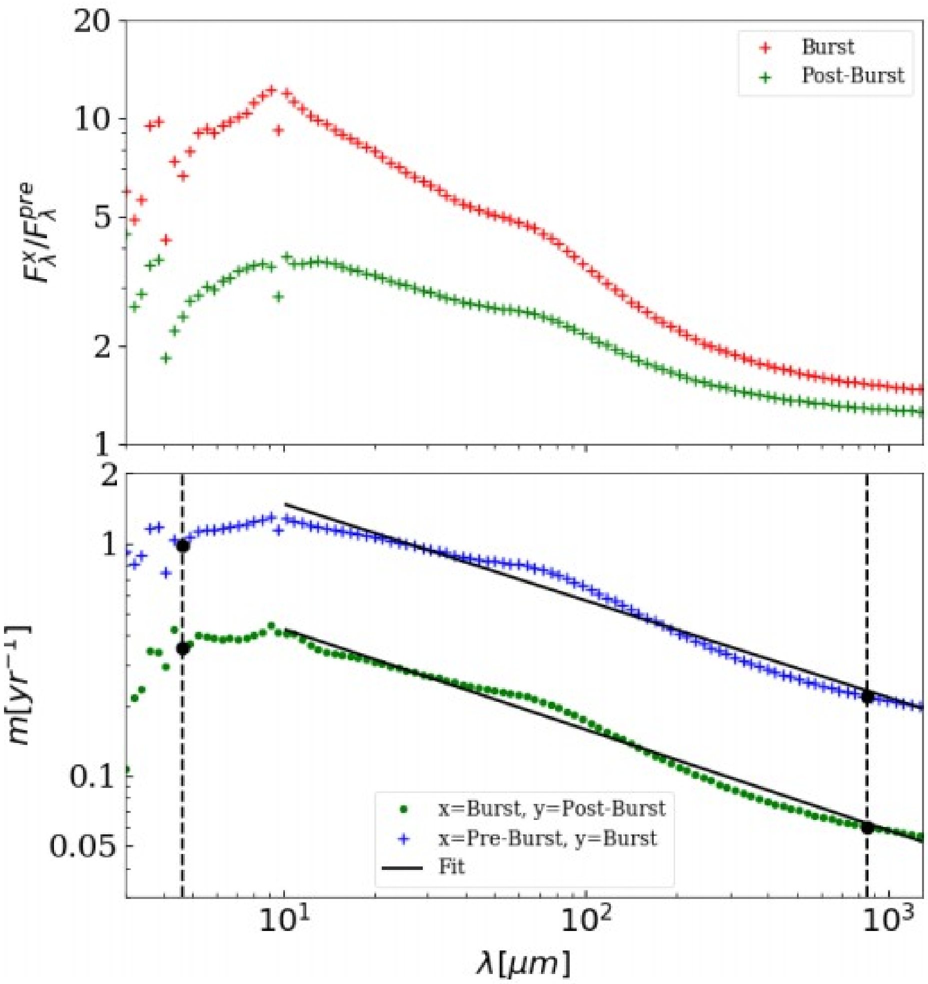
Methanol desorption red: ~ optimum 120-125 K, yellow: limit 94 K

Stecklum et al. submitted

Wavelength and flux dependence of flux variations

Rise and decent of the G358 burst

Wavelength dependence at λ>10μm following a power law



Stecklum et al. submitted

Summary

- CH_3OH maser flares are excellent proxies for accretion variability in HMYSOs

- Disk-mediated accretion bursts observed from low- to high-mass YSOs

- Variety of outburst strength in HMYSO – similar to low-mass counterparts

- Ejection bursts seen after accretion burst