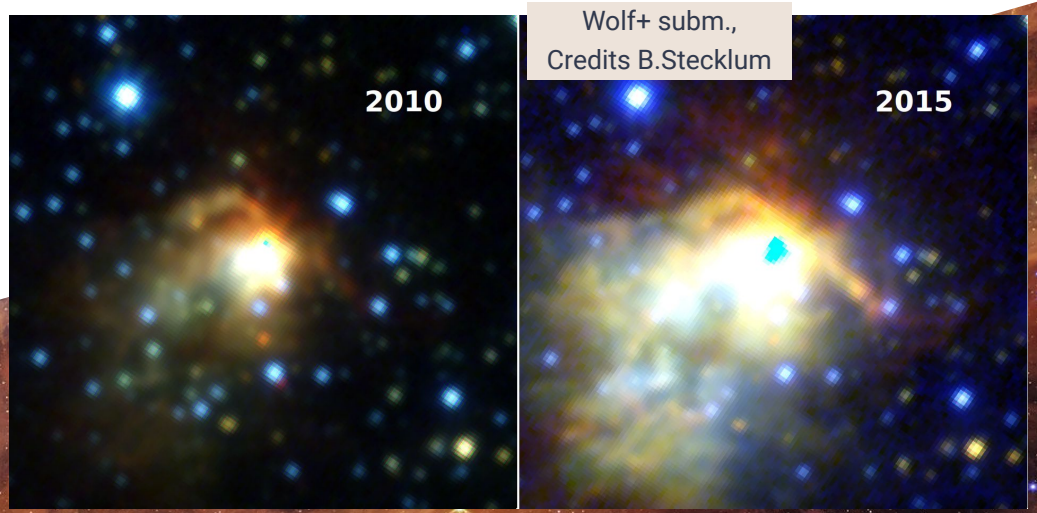
The accretion burst of G323.46 -0.08

Verena Wolf, Bringfried Stecklum, Jochen Eislöffel, Alessio Caratti o Garatti, Tim Harries, Christian Fischer, Hendrik Linz, Paul Boley, Aida Ahmadi, Julia Kobus, Xavier Haubois, Pierre Cruzalebes, Alexis Matter & the M2O Collaboration

Could it have triggered protostellar pulsations?

verena@tls-tautenburg.de



Wolf+ subm.,
Credits B.Stecklum

Fig: NIR image of G323 before and during its burst

Background image: NGC 3324, captured by the James Webb Space Telescope. Credits: NASA, ESA, CSA, and STScI

The accretion burst of G323.46 -0.08

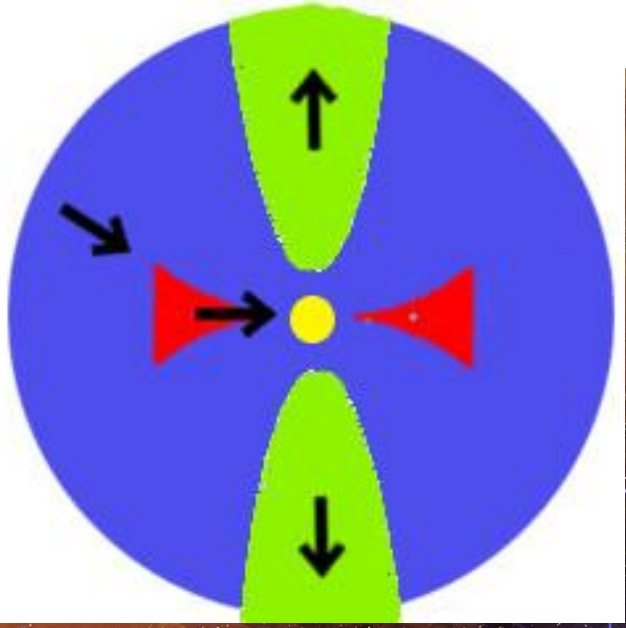
A fairly simple picture of a forming star

protostar

disk

envelope

bipolar outflow cavity



The accretion burst of G323.46 -0.08

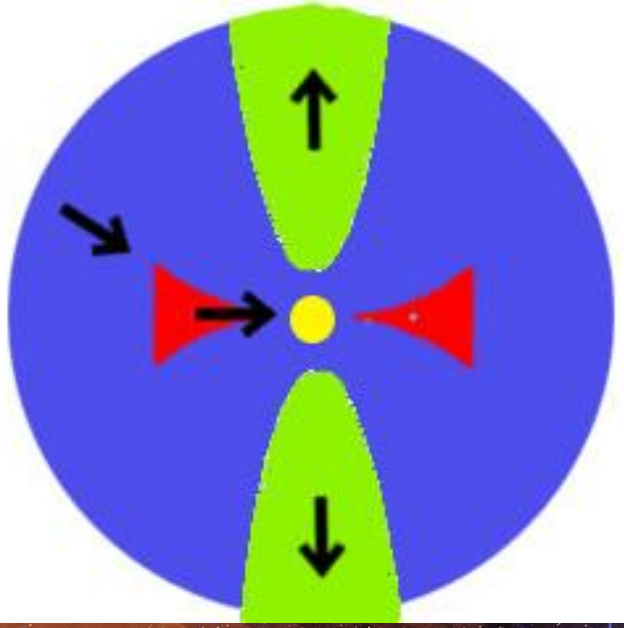
- Disk-mediated accretion
- Results in episodic accretion outbursts

protostar

disk

envelope

bipolar cavity



The burst of G323.46 -0.08 (G323)

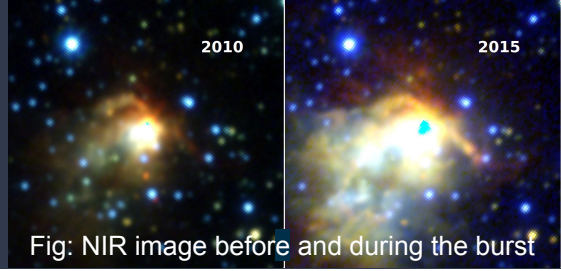


Fig: NIR image before and during the burst

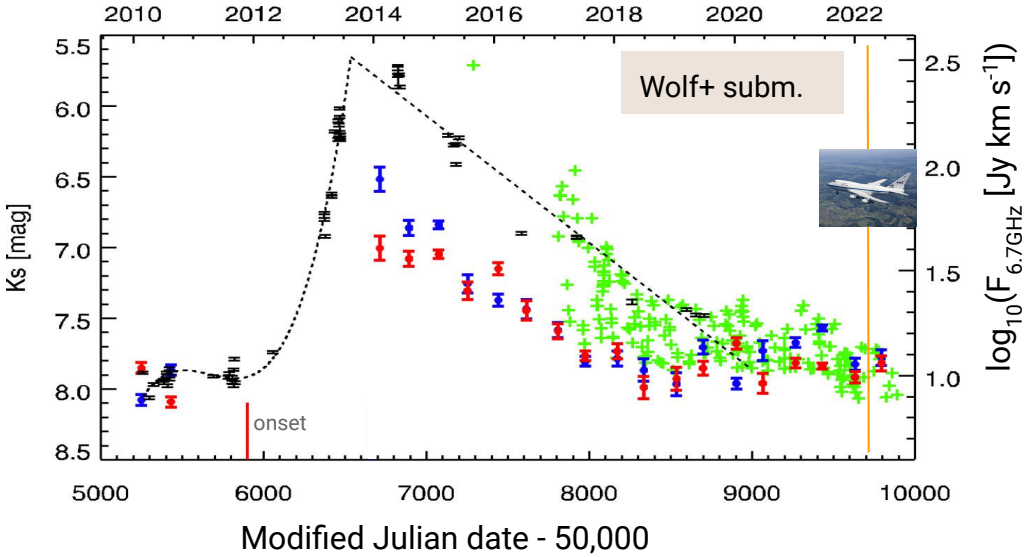


Fig: **Ks light curve**, velocity integrated maser flux and (NEO)WISE fluxes (red/blue, shifted to match Ks)

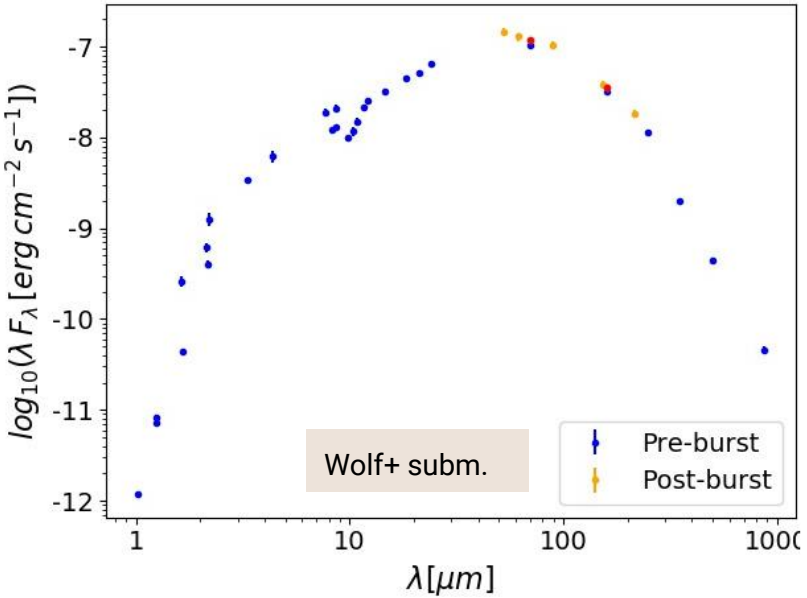


Fig: G323's pre- and post-burst (orange/red) SED

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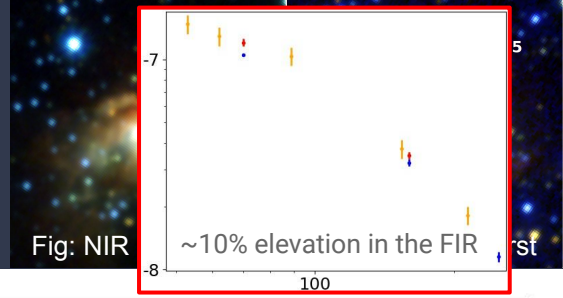
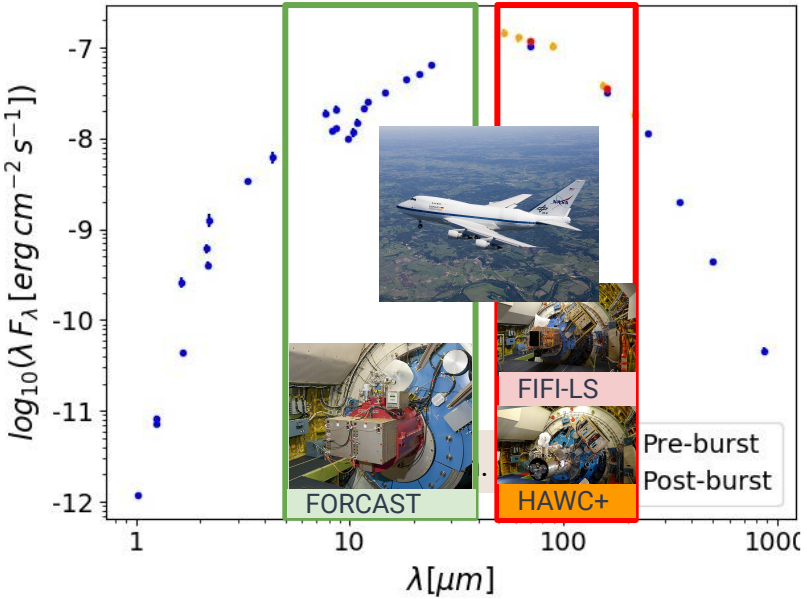


- Bursts cause a brightening at all wavelengths due to enhanced thermal dust emission (afterglow)
- SOFIA was crucial for deriving main burst parameters of MYSO bursts
  - e.g., [Caratti o Garatti+ 2017, Stecklum+ 2021, Hunter+ 2021]

Ks [mag]

Fig: **Ks light curve**, velocity integrated maser flux and (NEO)WISE fluxes (red/blue, shifted to match Ks)



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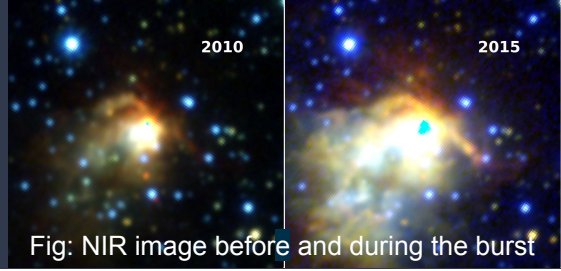

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More on Thursday:
talk of Bringfried Stecklum

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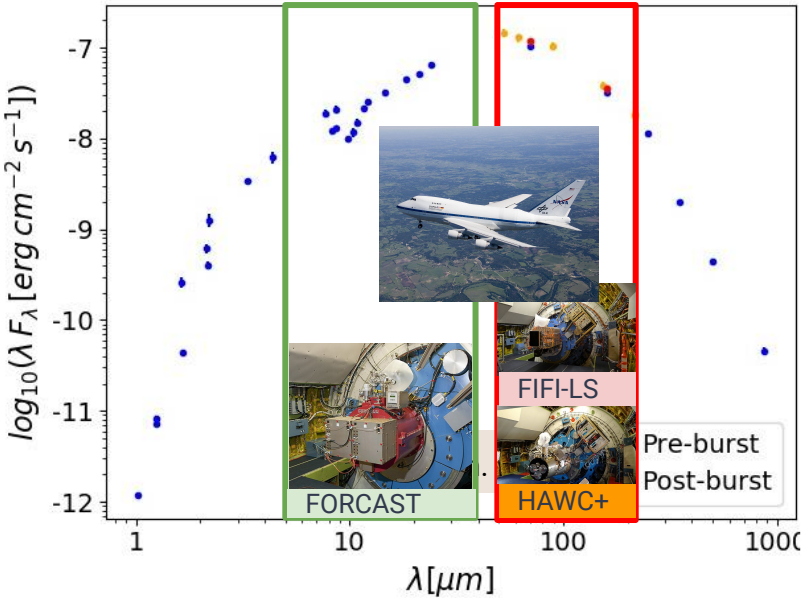
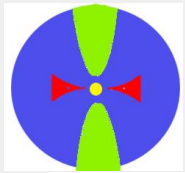
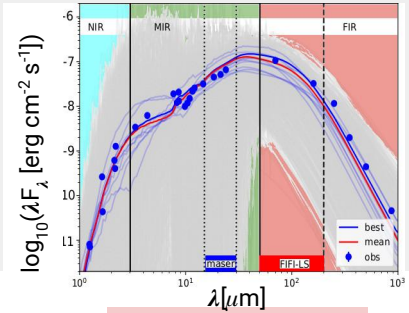


Fig: G323's pre- and post-burst (orange/red) SED

The static **pre-burst** model

density grid





Bolometric luminosity:

$L_{pre} = (6.1 \pm^{4.2}_{2.5}) 10^4\, L_\odot$

Harries+ 2019

output: SED

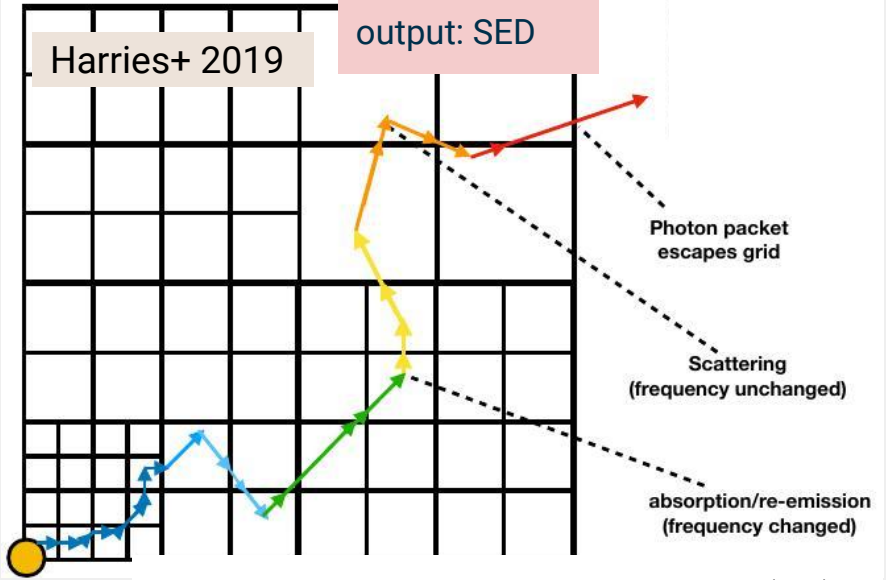
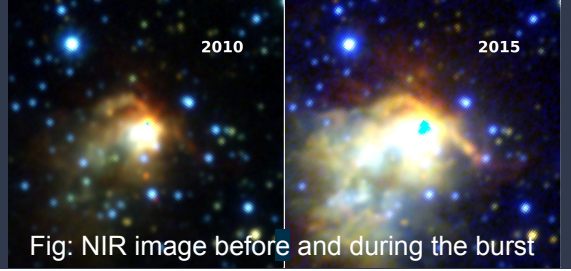


Fig: Schematics of **radiative transfer (RT)**

G323



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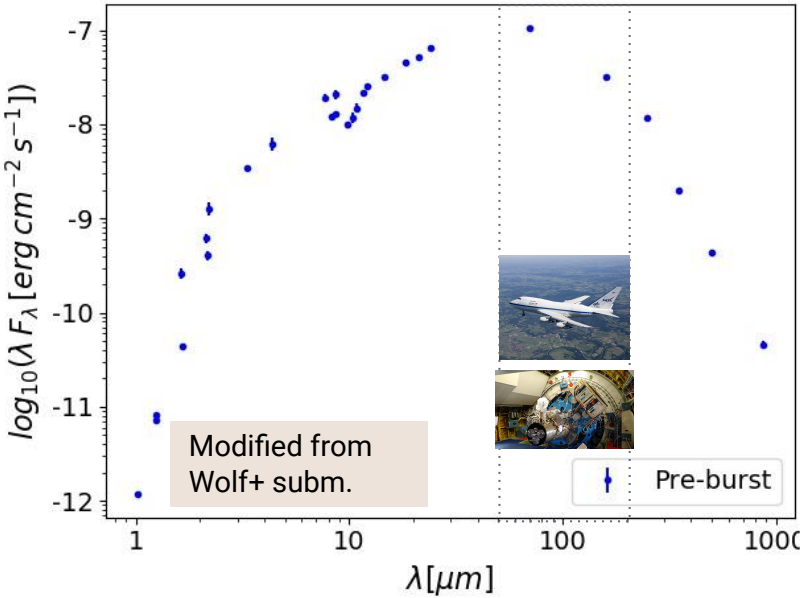
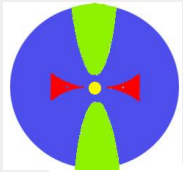


Fig: G323's pre-burst SED

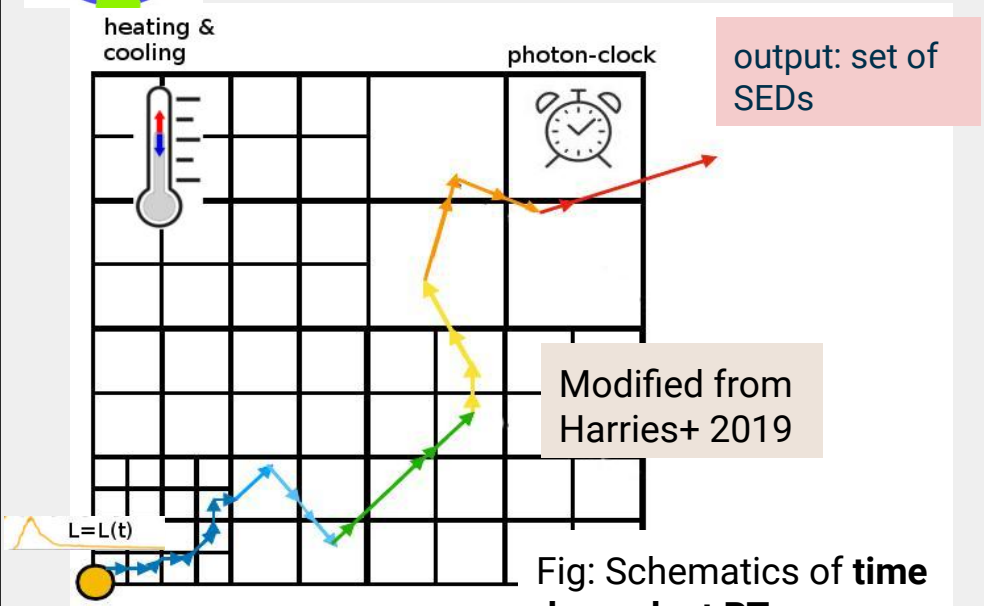
From static to **time dependent** RT

the burst parameters

density grid



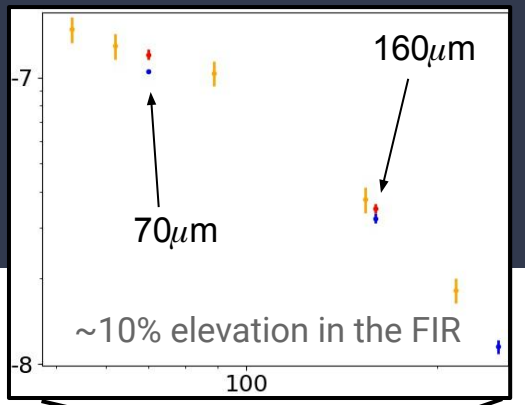
Versatile code, works for arbitrary density grids and luminosity variations

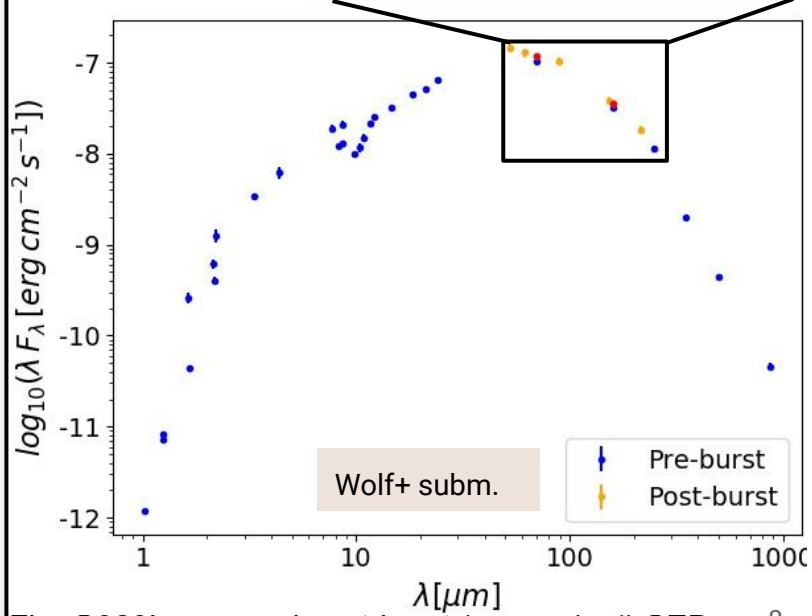


output: set of SEDs

Modified from Harries+ 2019

Fig: Schematics of **time dependent RT**





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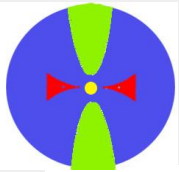

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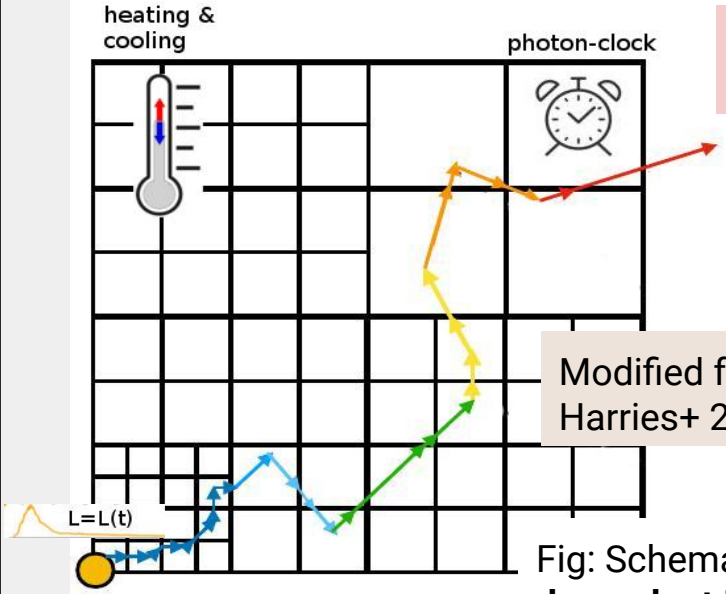

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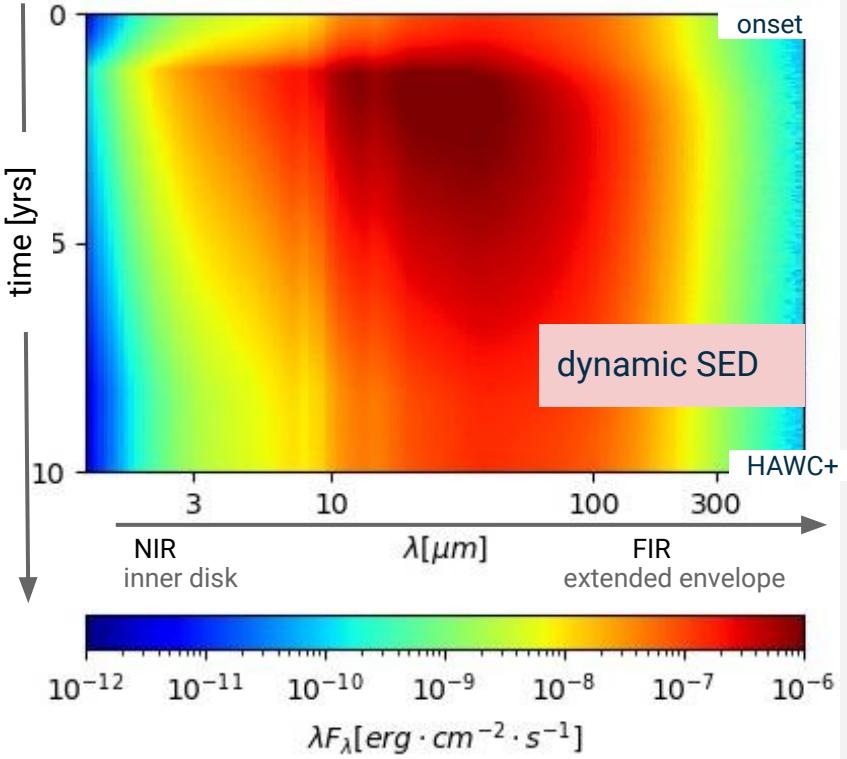
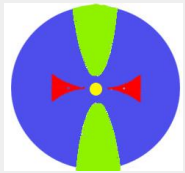


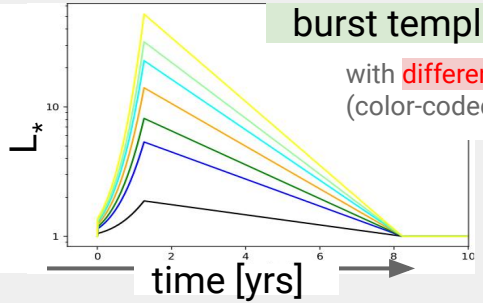
Fig: The dynamic SED, showing the flux density (color-bar) over wavelength and time for a particular G323 model

with different density grids



burst templates

with different burst energies (color-coded)



Likely the most energetic burst observed for a MYSO:

$$E_{acc} = (0.9 \pm^{2.5}_{0.7}) 10^{47}\ \mathrm{erg}$$

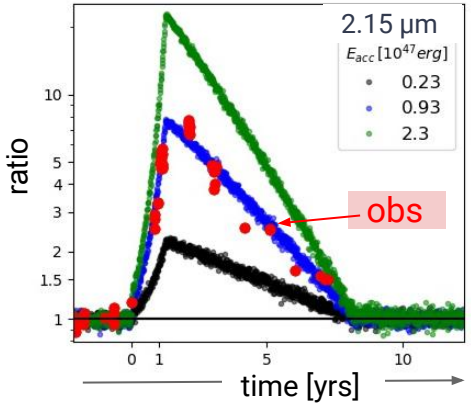


Fig: Ks light curve for three different burst energies (color-coded).

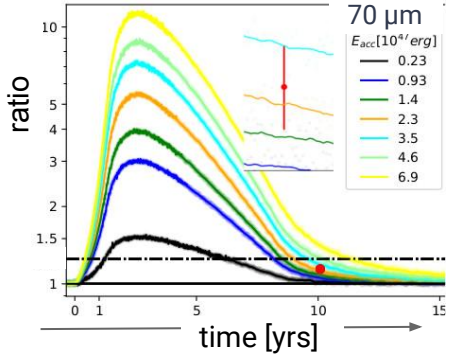
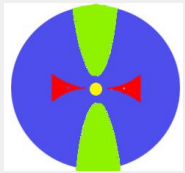


Fig: FIR light curve for different burst energies (color-coded). The inset shows the comparison to the HAWC+ data

Fig:

with different density grids



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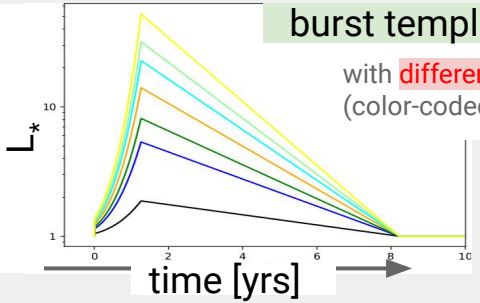

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$$L_{pre} = (6.1 \pm^{4.2}_{2.5}) 10^4\,\mathrm{L}_\odot$$
$$M_* = (23 \pm^{5}_{4})\,M_\odot$$
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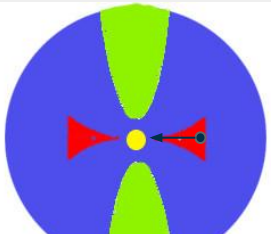
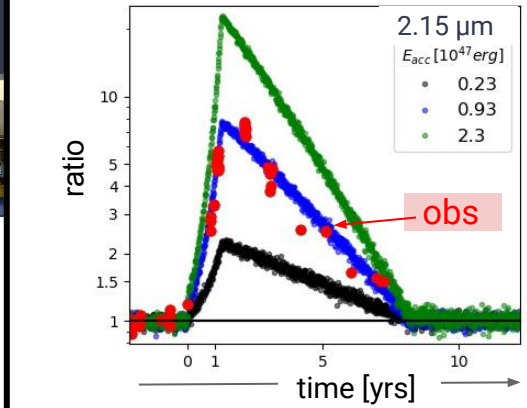
parameters for a protostar close to the main sequence (ZAMS)



Release of E_{pot}

$$M_{acc} = (7.3 \pm^{20}_{5.9})\,\mathrm{M_{Jup}}$$

Comparable to a big Jupiter, a disk fragment or a brown dwarf



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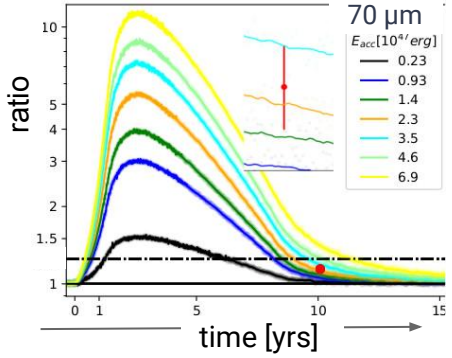

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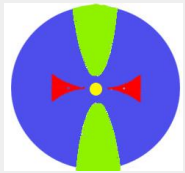
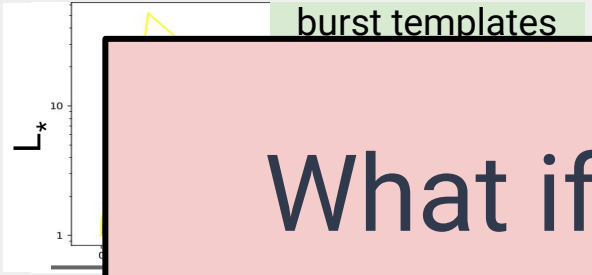
Fig:

What if G323 is bloated?

with different density grids

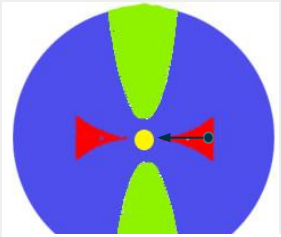


burst templates



Likely the most ene

E_{ac}



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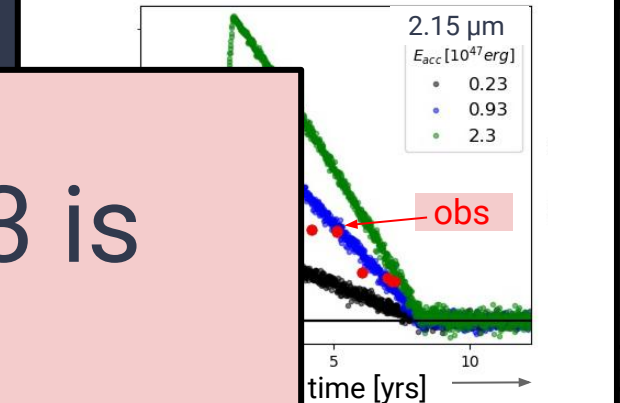
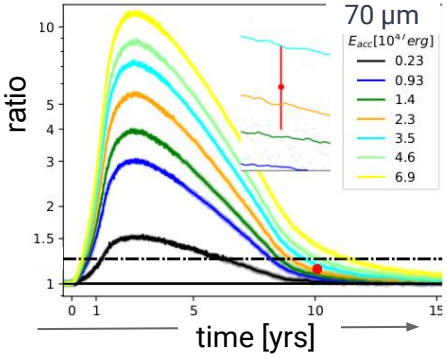
Comparable to a big Jupiter, a disk fragment or a brown dwarf



60μm

or three different burst ed).



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$log_{10}(\lambda F_\lambda [erg\, cm^{-2}$

e-burst
st-burst
1000

Fig:

ED

What if G323 is bloated?

- Much higher accreted mass
- Pulsation-instable for high accretion rates

with different density grids

burst templates

Likely the most ene

E_{ac}

$L_{pre} = (6.1 \pm^{4.2}_{2.5}) 10^4\,L_\odot$

M

R_*

with $M_{acc} = \frac{E_{acc} \cdot R_*}{G \cdot M_*}$

$g\,cm^{-2}\,s$

para to

M_{acc}

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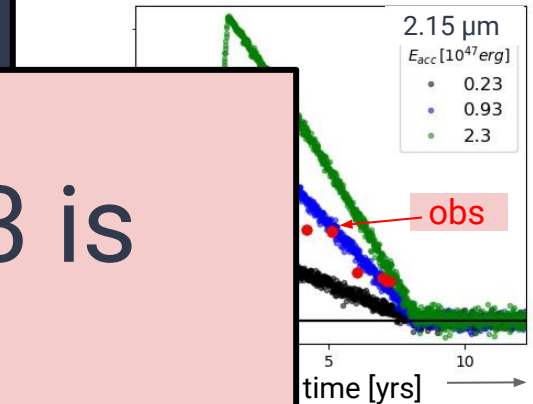

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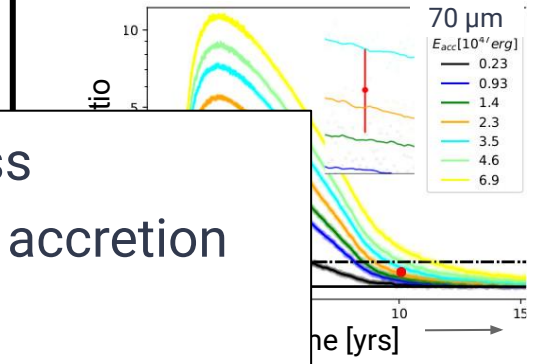

or different burst
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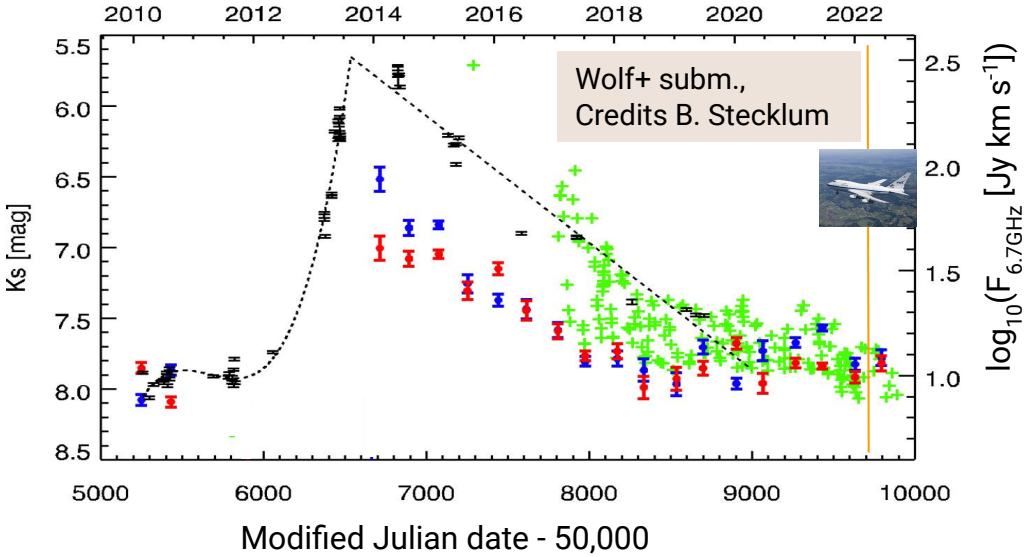
Fig:

60μm

e-burst
st-burst

1000

The burst of G323 – does G323 pulsate?



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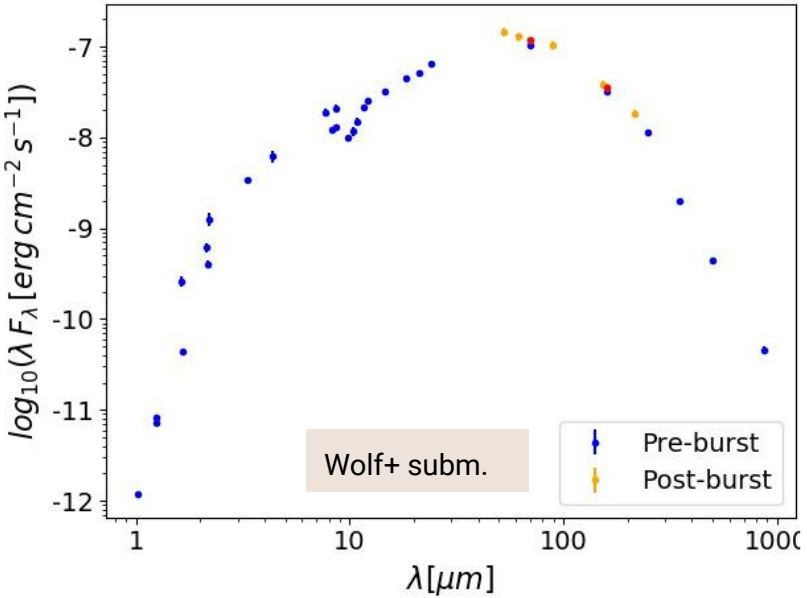

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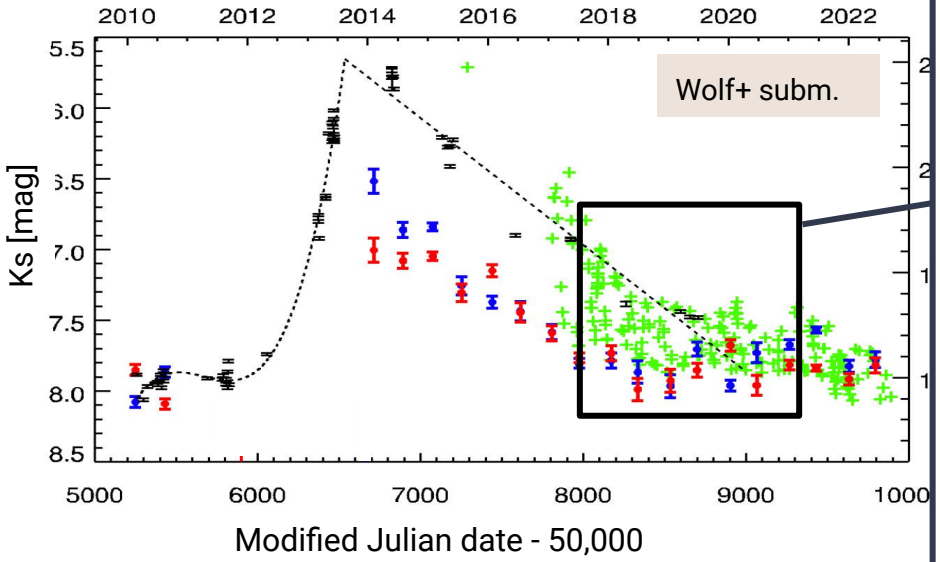

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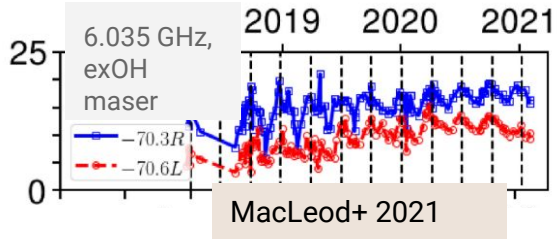
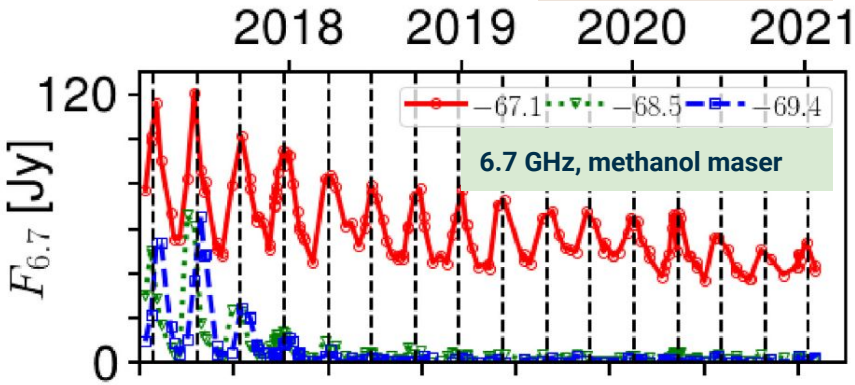
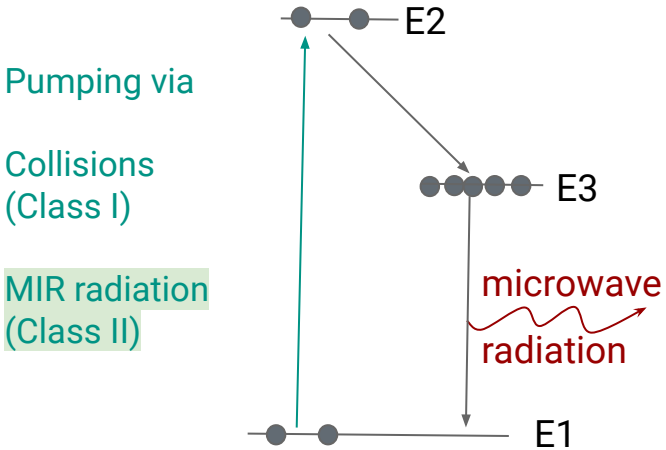




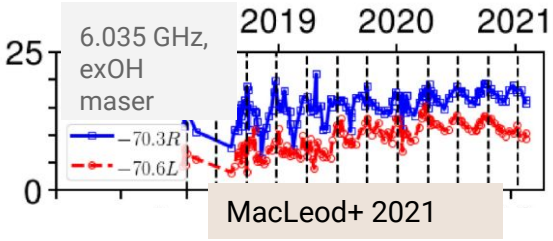
- Flare + damped oscillation
- 93.5 d period

Maser - the ‘microwave pendant of a laser’

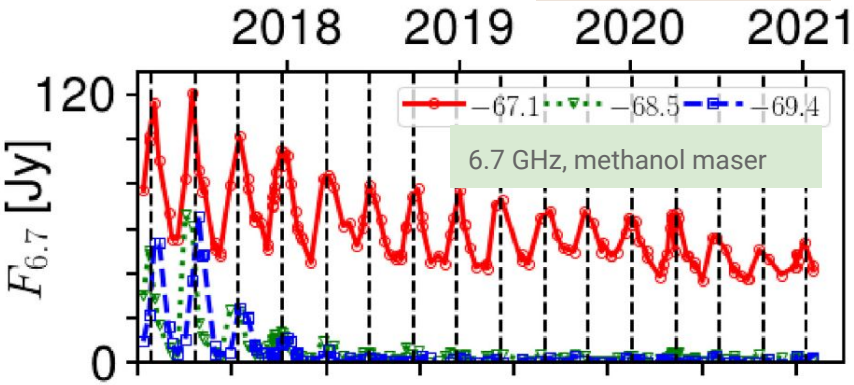
Microwave **A**mplification by **S**timulated **E**mission of **R**adiation



Class II methanol maser flares are burst alerts!



MacLeod+ 2021



- Flare + damped oscillation
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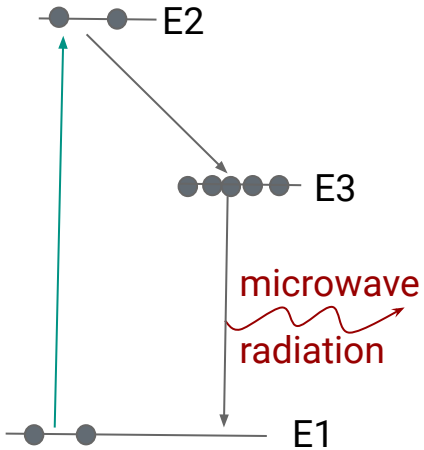
Maser - the ‘microwave pendant of a laser’

Microwave **A**mplification by **S**timulated **E**mission of **R**adiation

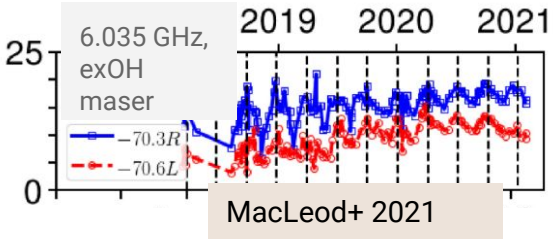
Pumping via

Collisions (Class I)

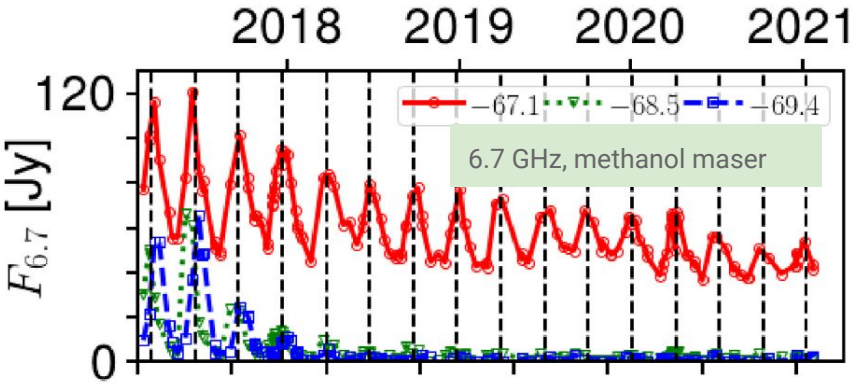
MIR radiation (Class II)



Class II methanol maser flares are burst alerts!



MacLeod+ 2021



- Flare + damped **oscillation**
- Flare + periodic background variations?
  - [Proven-Adzri+ 2019, MacLeod+ 2021]
- Flare + protostellar pulsations?
  - [Inayoshi+ 2013]

The burs

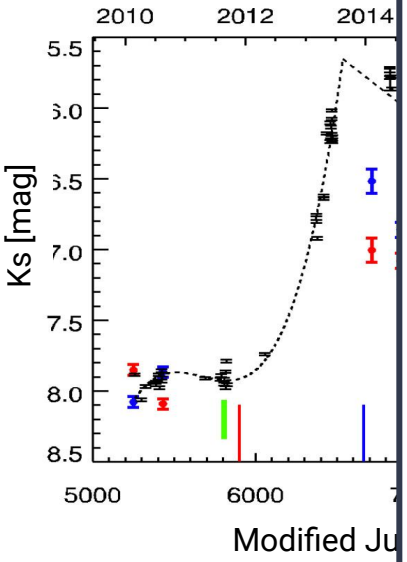


Fig: **Ks light curve**, velocity
fluxes (red/blue, shifted to

protostellar pulsations

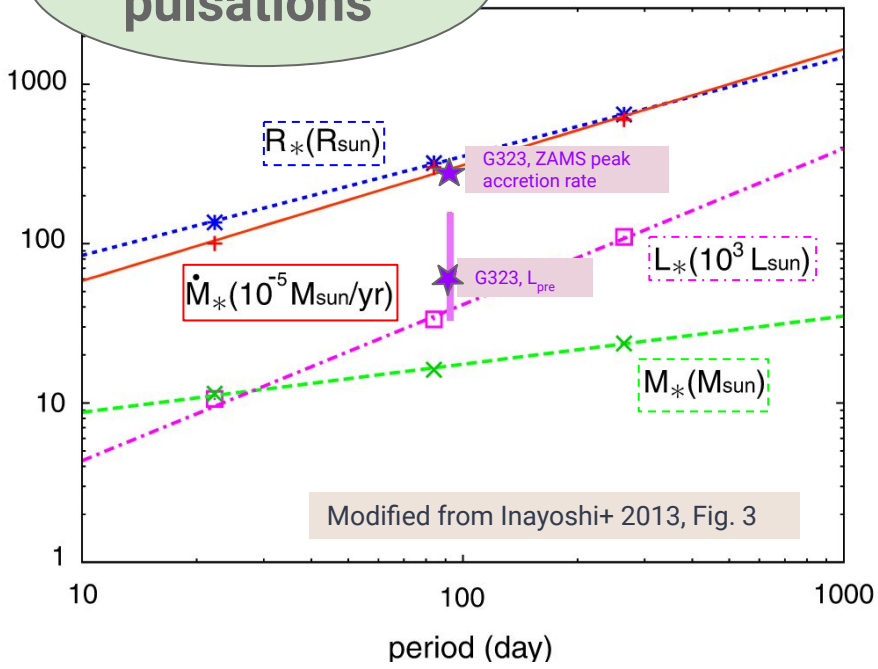
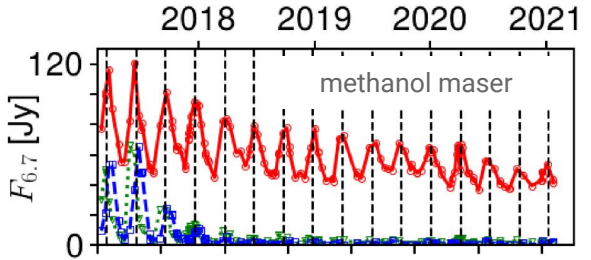
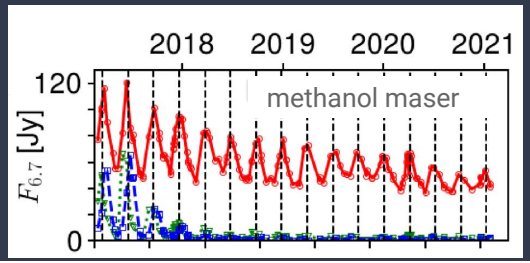


Fig: Period relations for pulsating protostars using spherical accretion models



- Period and luminosity are consistent with predictions from [Inayoshi+ 2013]
- Requires a bloated protostar (~300 $R_\odot$) and high accretion rates (~$3 \cdot 10^{-3}$ $M_\odot$ yr^{-1})
- Possibly the burst induced pulsations (?)

The burst of G323



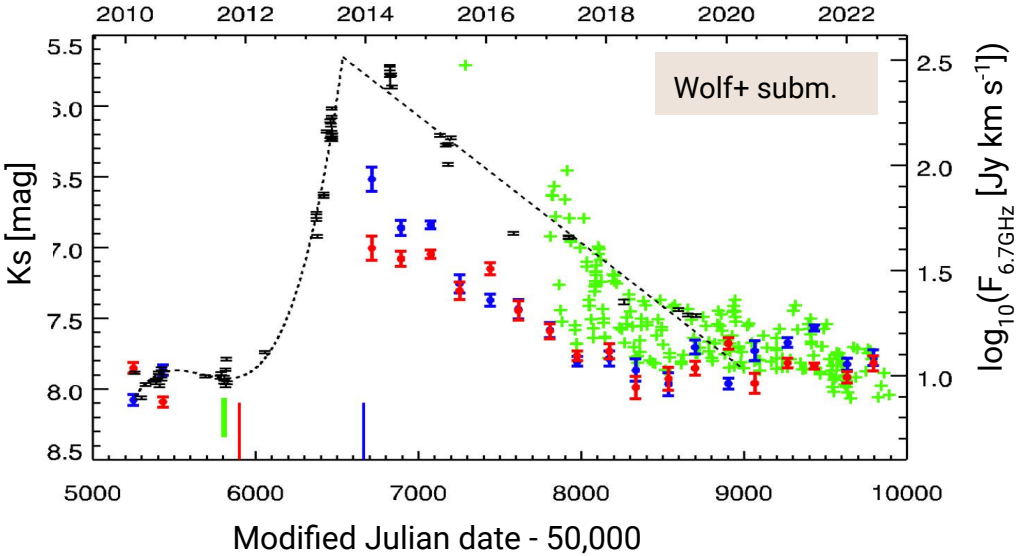


Fig: **Ks light curve**, velocity integrated maser flux and (NEO)WISE fluxes (red/blue, shifted to match Ks)

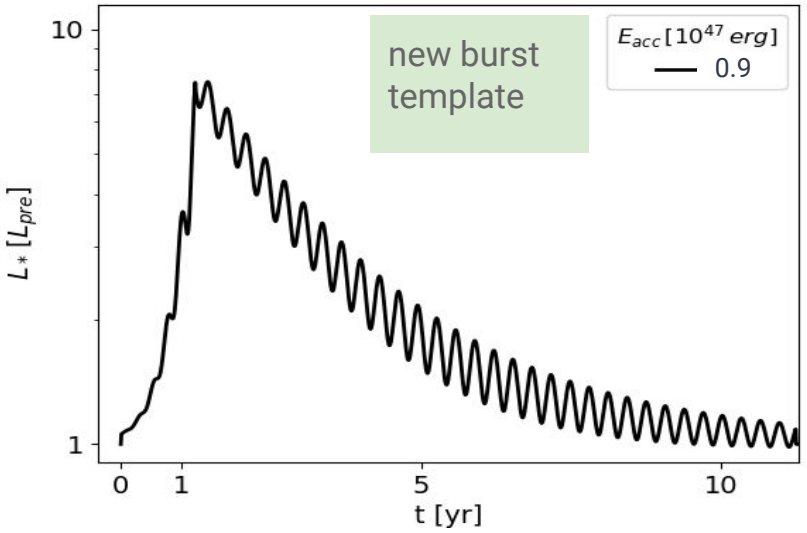
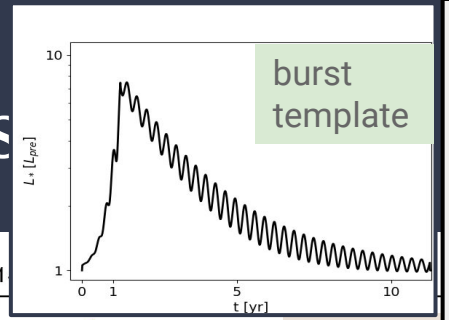
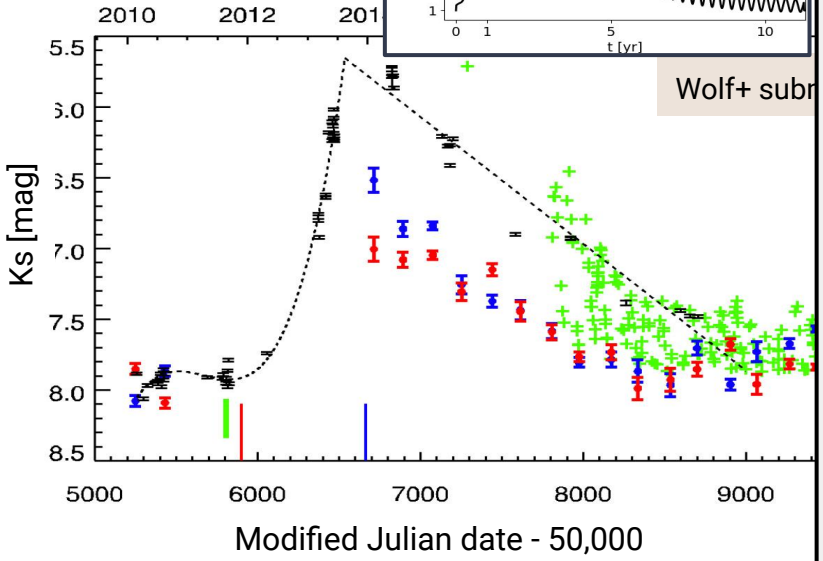


Fig: New burst template, featuring a burst with a polynomial decay + a damped oscillation

The burs





Wolf+ subr

Fig: **Ks light curve**, velocity integrated maser flux and (N
fluxes (red/blue, shifted to match Ks)

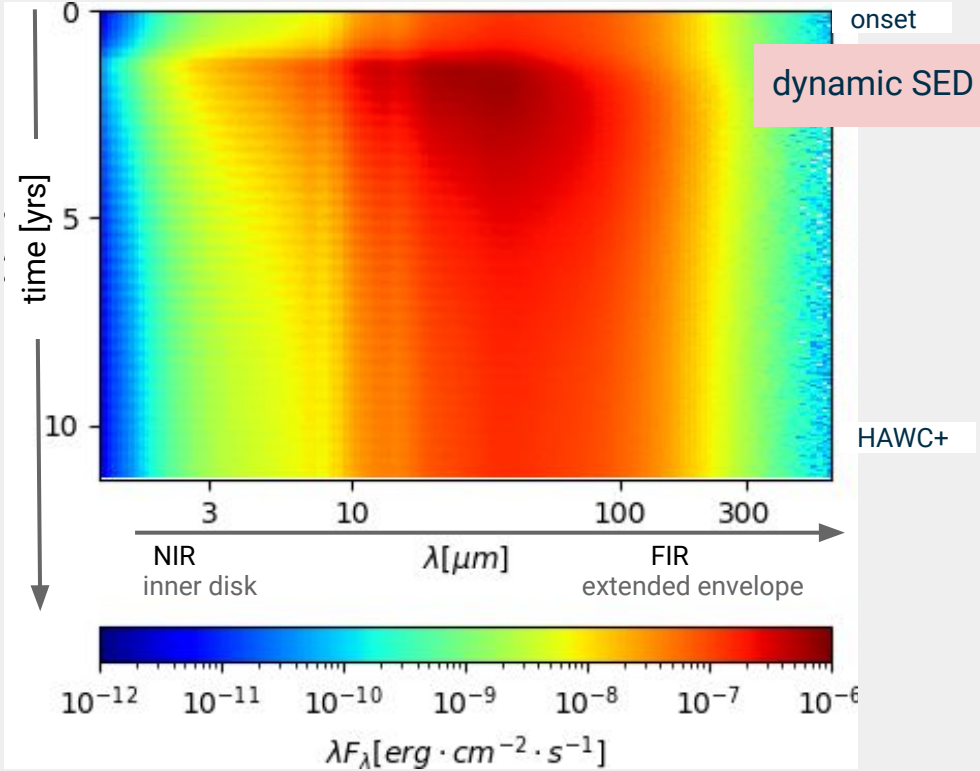


Fig: The dynamic SED, showing the flux density (color-bar) over wavelength and time for a particular G323 model. The **pulsation ripples** are seen **only at short wavelengths**

before

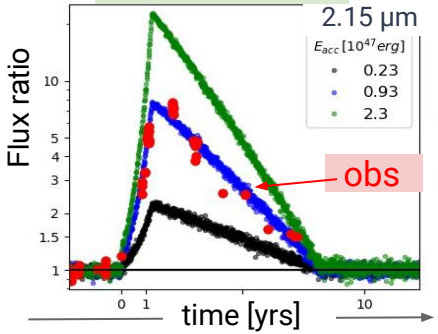


Fig: K light curve for three different burst energies (color-coded).

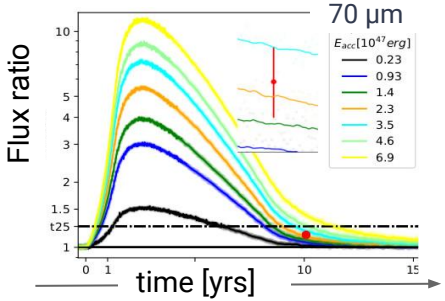
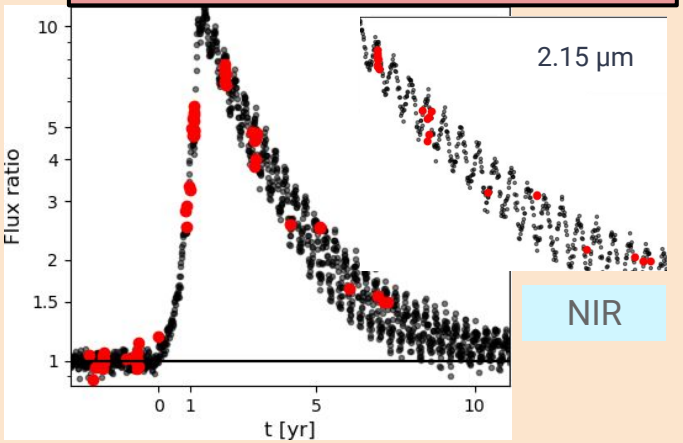
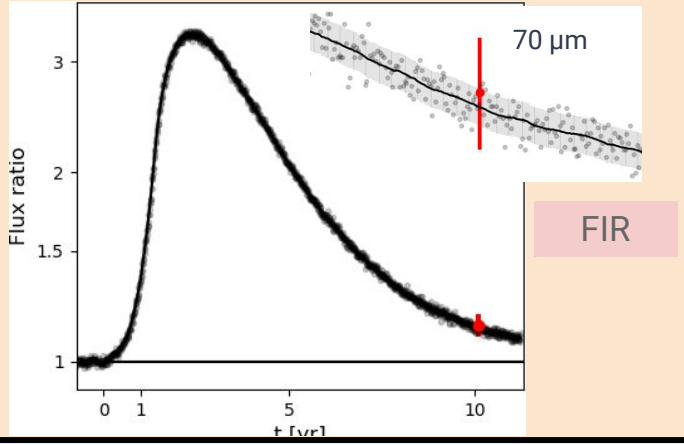


Fig: FIR light curve for different burst energies (color-coded). The inset shows the comparison to the HAWC+ data

agrees well with the observations





in the maser-regime

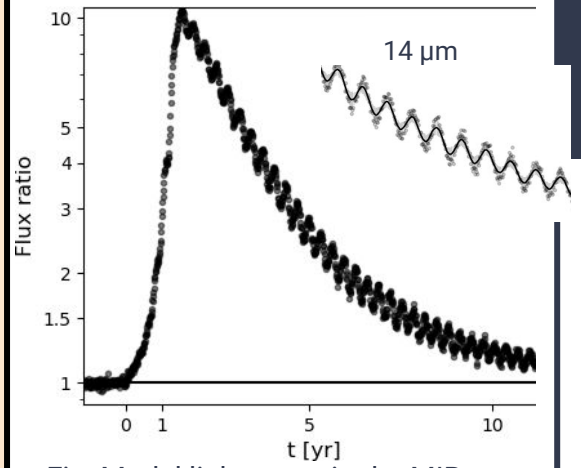


Fig: Model light curve in the MIR pumping regime

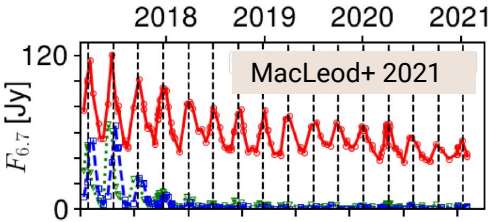
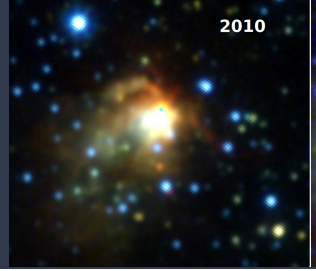
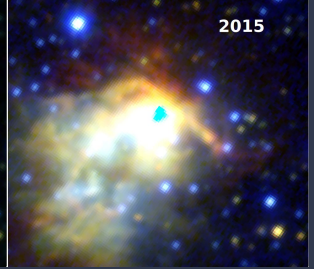


Fig: Methanol maser observations

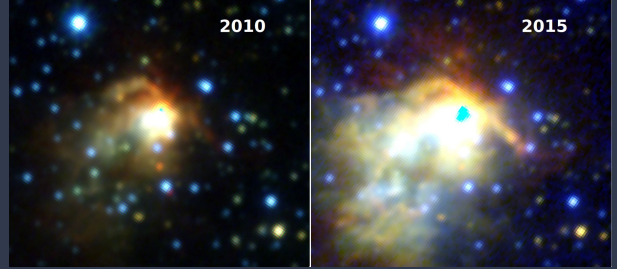
Summary and Outlook





- G323 experienced the most energetic accretion outburst observed so far
- G323 might be a pulsating protostar
  - In this case ...
    - ... it is/was bloated
    - ... the accreted mass can be much higher
  - We aim for ...
    - ... NIR spectroscopy with CRIRES+
    - ... modeling of (burst-induced) pulsations
  - Possibly the burst induced pulsations (?)
- Future bursts with periodic maser patterns (?)

Thanks for your attention!



- G323 experienced the most energetic accretion outburst observed so far
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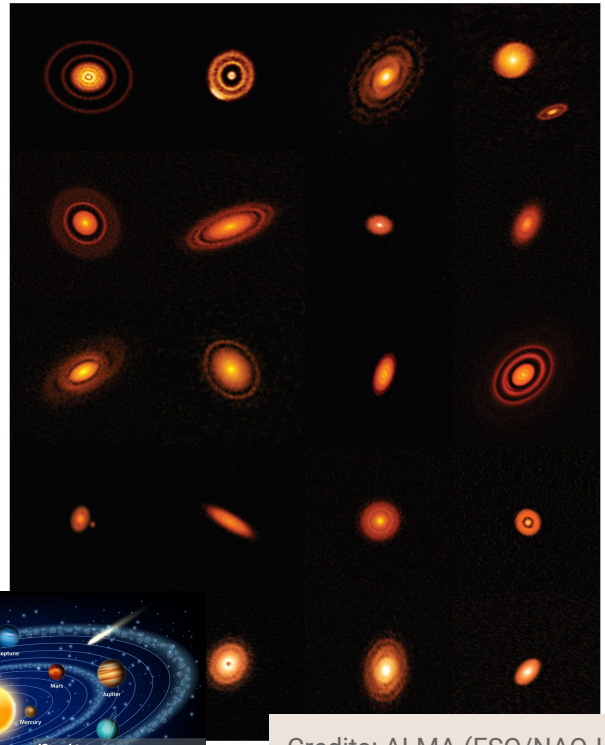
Questions ?

Low mass star formation



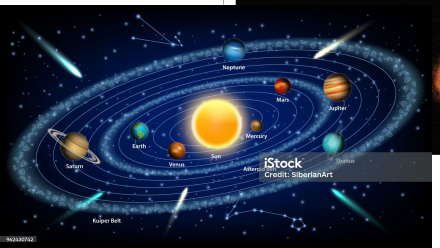
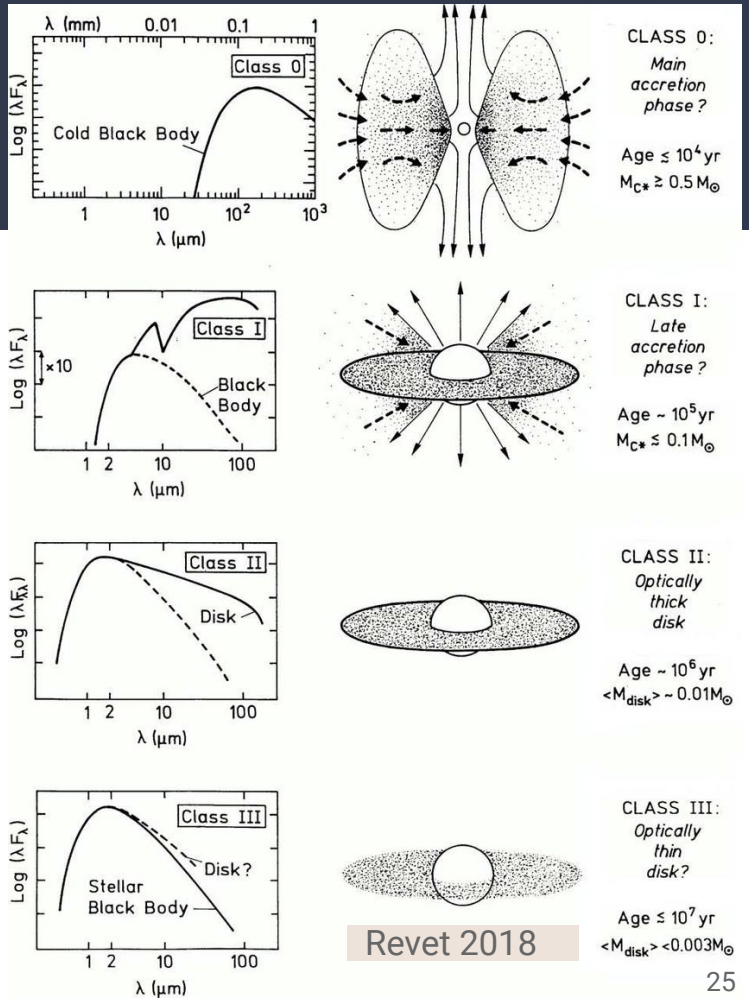


Fig: Protoplanetary disks from the DSHARP program (ALMA)

Credits: ALMA (ESO/NAOJ/NRAO), Andrews+; NRAO/AUI/NSF, S. Dagnello

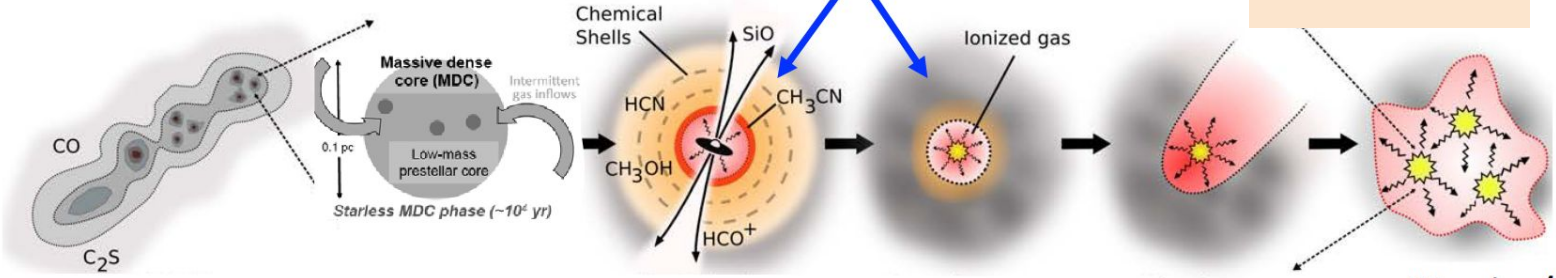


Revet 2018

Observation-based stages of Massive Star Formation

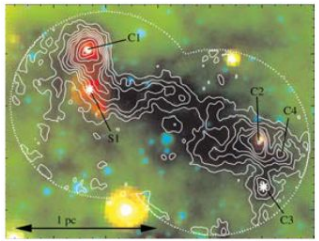
COMs: Complex Organic Molecules

Hunter 2019



clumpy molecular cloud

L ~ several pc

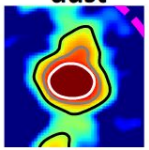


e.g. G19.30+0.07
Devine+2011

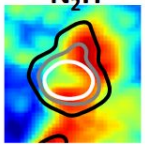
massive prestellar cores (very elusive)

R < 0.1 pc

dust



N_2H^+



e.g. G11.92-0.61MM2
Cyganowski+2014

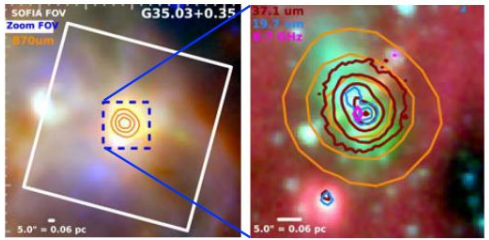
hot molecular core

hypercompact HII region

R < 1000 au

Not distinct stages; incl. EGOs 4.5um

accretion outbursts occur here



e.g. G35.03+0.35, Towner+2018

ultracompact HII region

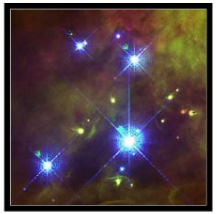
R < 10000 au

modest time variability (DePree+2018)

e.g. G29.96-0.02
Kalcheva+2018

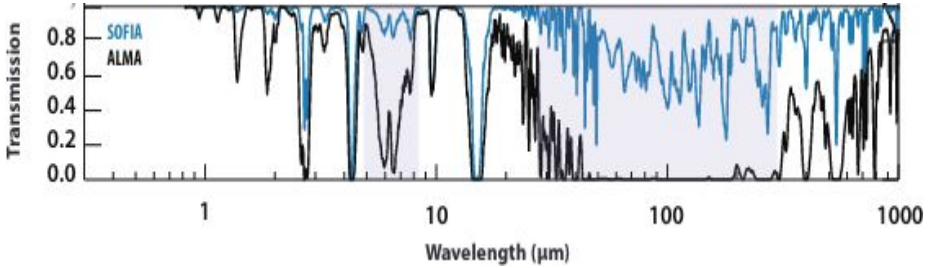
HII region / OB association

R > 0.1pc



Orion Trapezium
Bally+1998

Atmospheric transmission and episodic accretion



Meyer+ 2019

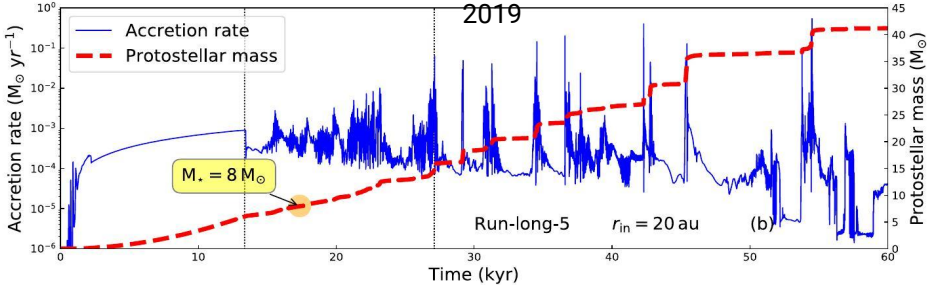
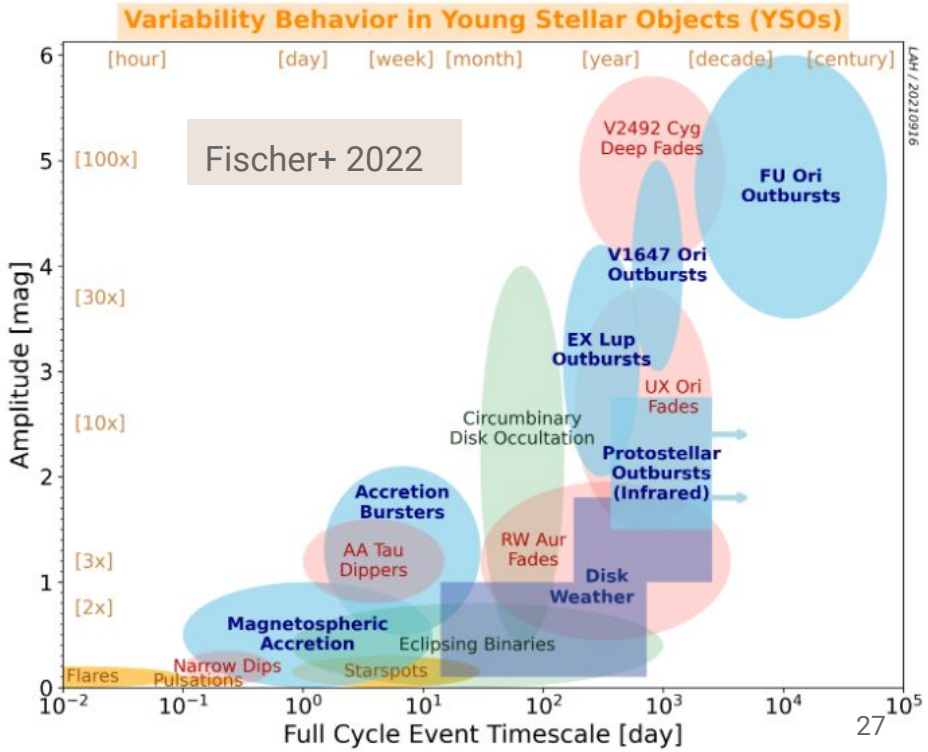


Fig: Modeled protostellar mass and accretion rate as a function of time



The sample of known MYSO bursts

System	$M_\star$	$L_\star^{pre}$	L_{peak}	ΔL	t_{rise}	Δt	$\dot{M}$	E_{acc}	M_{acc}
	$M_\odot$	$10^3 \cdot L_\odot$	L_{pre}	$10^3 L_\odot$	yr	yr	$10^{-3} \frac{M_\odot}{yr}$	$10^{45} \cdot erg$	M_{Jup}
NIRS3*	20	30	5.5	130	0.4	2.5	5	12	2
G358*	12	**5.0**	**4.8**	**19**	0.14	0.5	**1.8**	**2.8**	**0.5**
G323*	**23**	**60**	**5.4**	**260**	**1.4**	**8.4**	**0.8**	**90**	**7**
NGC*	6.7	3	16	44	0.6	>8	2.3	>40	>0.4
V723 Car	10?	≈ 4			4	≈ 15			
M17 MIR	5.4	1.4	6.4	7.6		9-20	≈ 2		

* accompanying maser flare

NIRS3 (S255IR NIRS3) [Caratti o Garatti+ 2017], G358 (G358.93-0.03-MM1) [Sugiyama+ 2019, Brogan+ 2019, **Stecklum+ 2021**, Burns+ 2020, 2022, 2023], G323 (G323.46-0.08) [Proven-Adzri+ 2019, **Wolf+ in prep.**], NGC (NGC 6334I MM1) [Hunter+ 2017], V723 Car [Tapia+ 2013, 2015], M17 MIR [Chen+ 2021]

Tab: The sample of known MYSO bursts. Bold values are derived within this work.

The YSO-grid

(aka sedfitter)

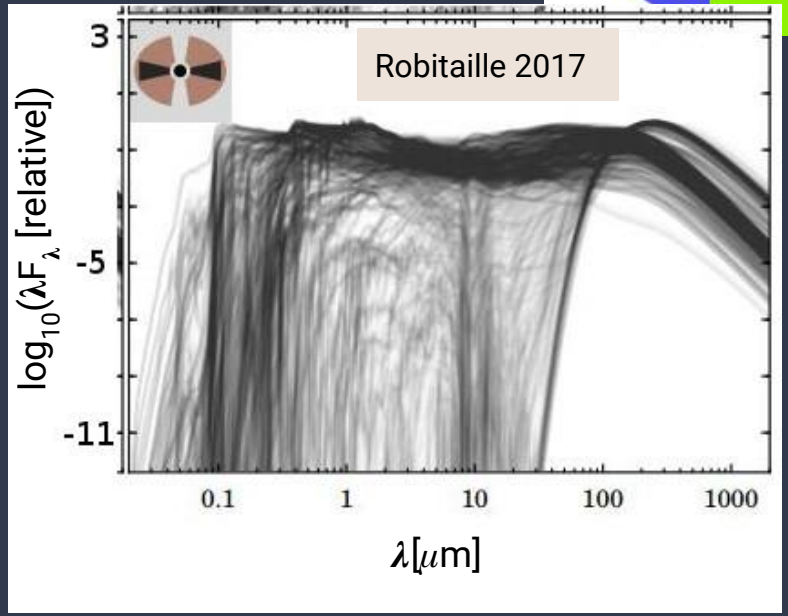
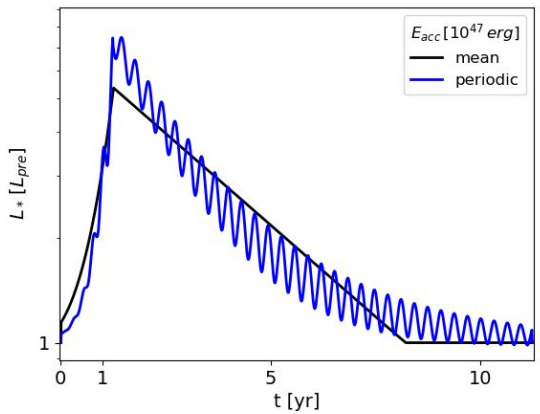
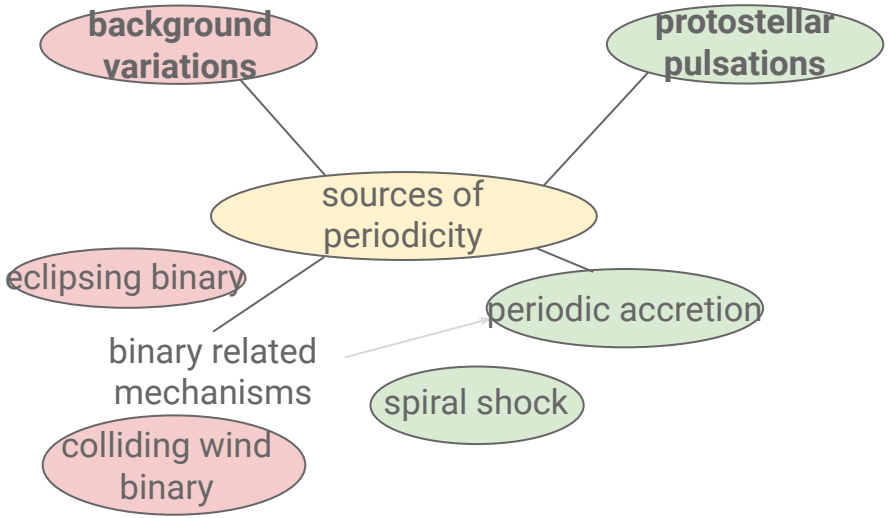


Fig: YSO-grid (set of static SEDs) used for the pre-burst fit

parameter		unit	samp	min	max
star	R_*	$R_\odot$	log	0.1	100
	T_*	$T_\odot$	log	2000	30,000
disk	m_{disk}	$m_\odot$	log	10^{-8}	0.1
	r_{disk}	au	log	50	5,000
	β_{disk}	-	lin	1	1.3
	p_{disk}	-	lin	-2	0
	h_{disk}	au	log	1	20
env	ρ_{env}	g/cc	log	10^{-24}	10^{-16}
cav	ρ_{cav}	g/cc	log	10^{-23}	10^{-20}
	Θ_{cav}	°	lin	0	60
	c_{cav}	-	lin	1	2
view	i	°	lin	0	90

Tab: Parameter-ranges of the models included in the YSO-grid. All masses/densities are dust properties.


$E_{acc}[10^{47}\,erg]$
mean
periodic
$L_*\,[L_{pre}]$
1
0
1
5
10
t [yr]


background variations
protostellar pulsations
sources of periodicity
eclipsing binary
periodic accretion
binary related mechanisms
spiral shock
colliding wind binary