Уральский федеральный университет имени первого Президента России Б.Н.Ельцина

Millimeter and submillimeter transient events in star formation

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Institute for Natural Sciences and Mathematics

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Submillimeter and Millimeter Astronomy: Objectives and Instruments
April 12-16, 2021, online

Transient events carry information on the sudden changes in the objects, their characteristic times are short and sometimes we can observe the whole duration of the event

Transient events are a kind of phase transitions and carry information on both prior- and post- evolutionary “phases” of the event. This makes studies of the transient events very informative

Monitoring is the only way to register and study transient events

Monitoring requires considerable observing time, especially for the studies of rare and long-duration events

Observing time of the mm and submm facilities is quite expensive at present. So, the era of extensive mm/submm monitoring should come in future

Anyhow, some research is ongoing now and brings good fruits

Types of monitoring
spectral, photometric

All-sky: using surveys WISE, GAIA,(AKARI?), etc.

Selected areas (maps): list of selected areas monitored with some chosen cadence

Selected targets: list of individual sources monitored with some chosen cadence (maser monitoring at Ibaraki U., PRAO ASC, etc.)

Triggered monitoring

All-sky: using surveys WISE, GAIA,(AKARI?), etc.

example

THE ASTROPHYSICAL JOURNAL, 883:6 (8pp), 2019

WISE Discovery of Mid-infrared Variability in Massive Young Stellar Objects

Mizuho Uchiyama[1] and Kohei Ichikawa[2,3]

Abstract

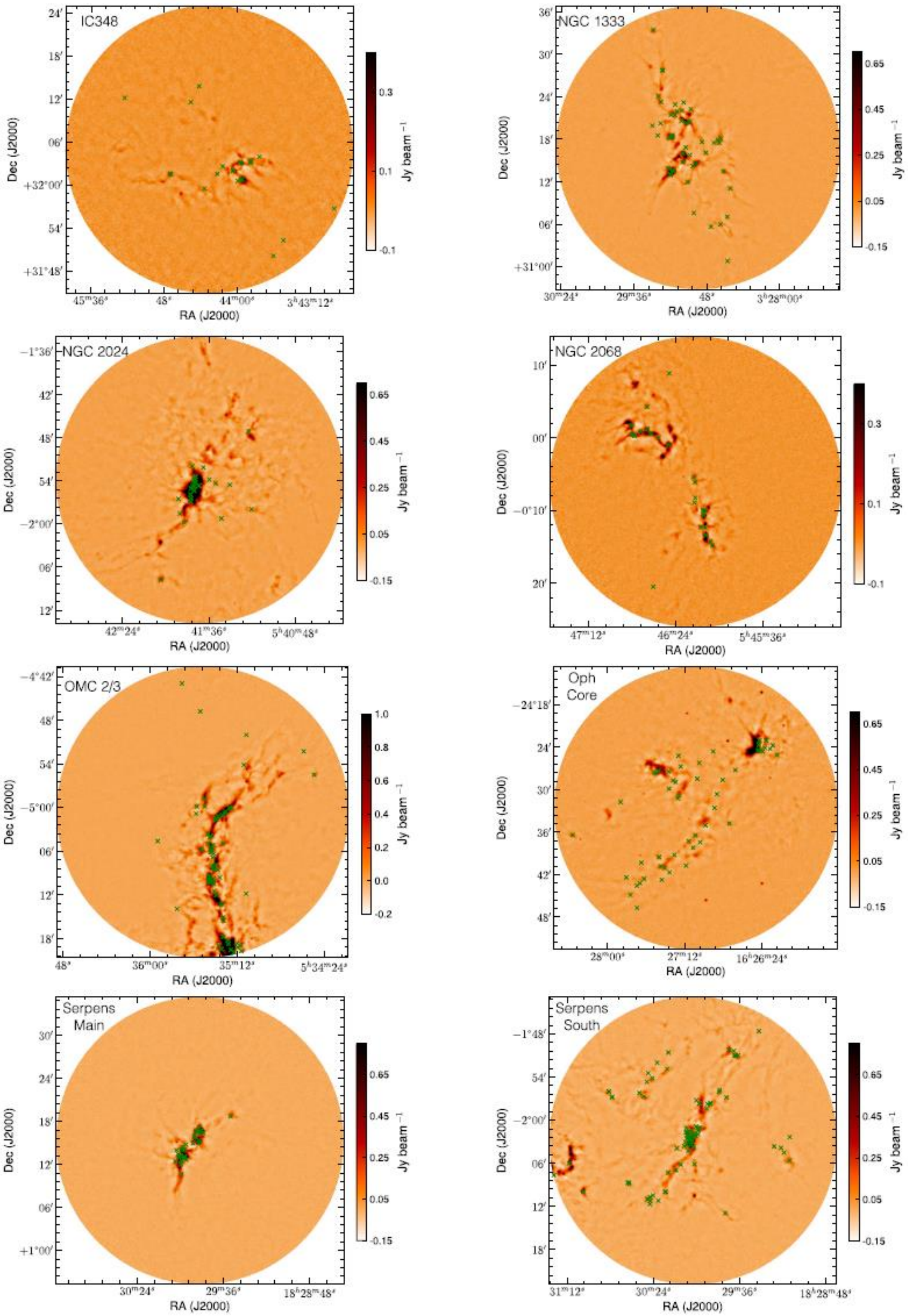
We systematically investigate the mid-infrared (MIR; $\lambda > 3\ \mu$m) time variability of uniformly selected ∼800 massive young stellar objects (MYSOs) from the Red *Midcourse Space Experiment* Source survey. Out of the 806 sources, we obtain reliable 9 yr long MIR magnitude variability data of 331 sources at the 3.4 μm (*W*1) and 4.6 μm (*W*2) bands by cross-matching the MYSO positions with ALLWISE and NEOWISE catalogs. After applying the variability selections using ALLWISE data, we identify five MIR-variable candidates. The light curves show various classes, with the periodic, plateau-like, and dipper features. Out of the obtained two color–magnitude diagram of *W*1 and $W1-W2$, one shows "bluer when brighter and redder when fainter" trends in variability, suggesting change in extinction or accretion rate. Finally, our results show that G335.9960−00.8532 (hereafter, G335) has a periodic light curve, with an ≈690 day cycle. Spectral energy density model fitting results indicate that G335 is a relatively evolved MYSO; thus, we may be witnessing the very early stages of a hyper- or ultra-compact H II region, a key source for understanding MYSO evolution.

Selected areas (maps): list of selected areas monitored with some chosen cadence

example

The JCMT Transient Survey

- Lee Y.-H. et al. 2020, ApJ, 903, 5 Young Faithful: The Eruptions of EC 53 as It Cycles through Filling and Draining the Inner Disk
- Contreras Peña C. et al. 2020, MNRAS, 495, 3614 The relationship between mid-infrared and sub-millimetre variability of deeply embedded protostars
- Mairs S. et al. EAO SUBMILLIMETRE FUTURES PAPER SERIES, 2019 "SUBMILLIMETRE TRANSIENT SCIENCE IN THE NEXT DECADE"
- Mairs S. et al. 2019, ApJ, 871, 72 The JCMT Transient Survey: An Extraordinary Submillimeter Flare in the T Tauri Binary System JW 566
- Johnstone D. et al. 2018, ApJ, 854, 31 The JCMT Transient Survey: Stochastic and Secular Variability of Protostars and Disks In the Submillimeter Region Observed over 18 Month
- Mairs S. et al. 2017, ApJ, 871, 72 The JCMT Transient Survey: Identifying Submillimeter Continuum Variability over Several Year Timescales Using Archival JCMT Gould Belt Survey Observations
- Herczeg G.J. et al. 2017, ApJ, 849, 43 How Do Stars Gain Their Mass? A JCMT/SCUBA-2 Transient Survey of Protostars in Nearby Star-forming Regions
- some more



8 regions of
low-mass-star formation
(6 high-mass-star formation
regions are added recently)

182 protostars
800 disk sources

1 month cadence

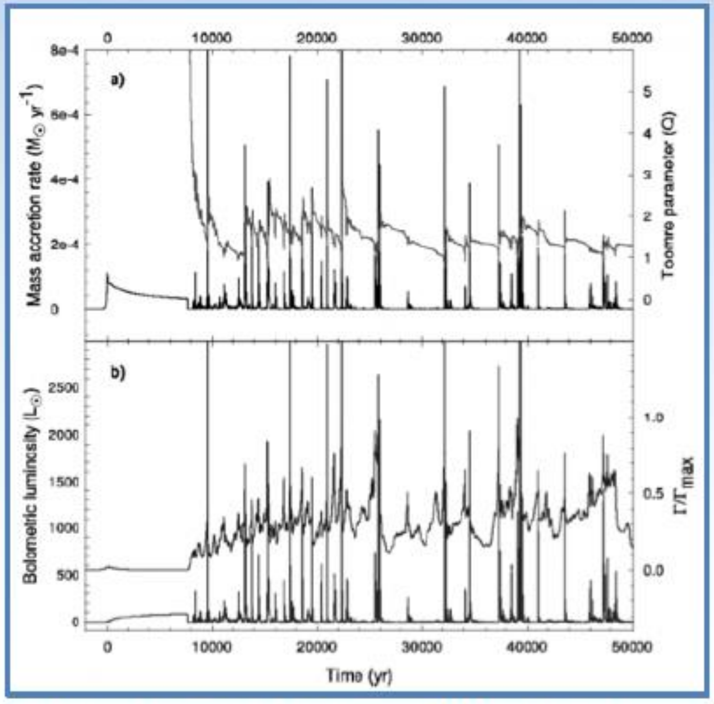
850 and 450 mkm

3 yr
(now extended to 7 years)

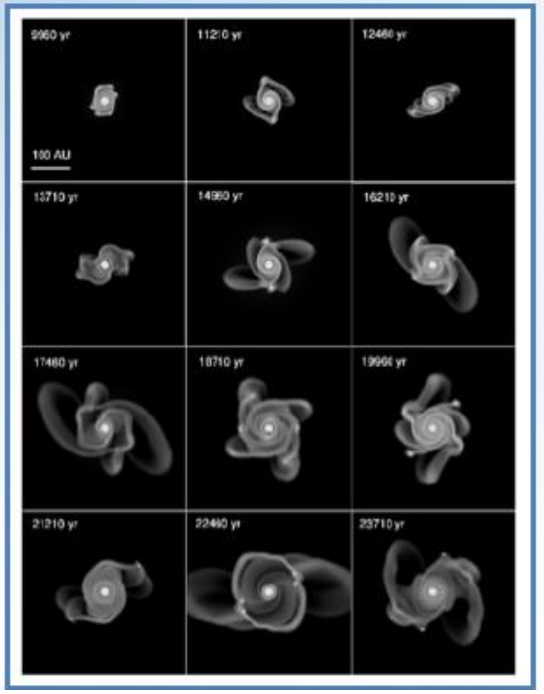
Herczeg+ 2017, ApJ, 849
Mairs+ 2017a, ApJ, 843
Yoo+ 2017, ApJ, 849, 69
Mairs+ 2017b, ApJ, 849
Johnstone+ 2018, ApJ, 854
Mairs+ 2019, ApJ, 871
Lee+ 2019, Nature Astro, 3
MacFarlane+ 2019a/b, MN 487
Park+ 2019, ApJS, 242
Baek+ 2020, ApJ, 895
Lee+ 2020, ApJ, 889
Contreras Pena+, 2020, MNRAS
Lee+ 2020, ApJ, accepted
Francis+ 2020, ApJ, submitted

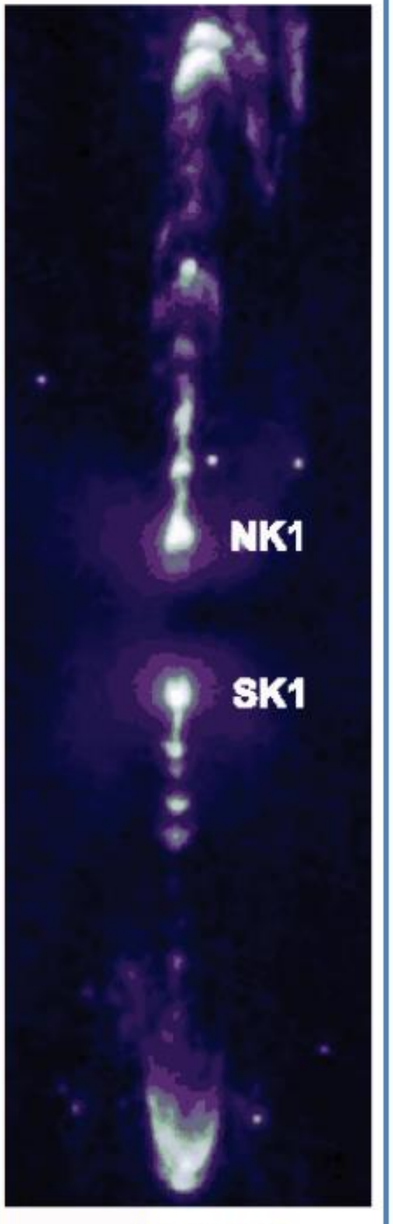
Mass Accretion – Non-Steady?

- Disk models suggest disk transport often ***inefficient***
  - Outer disk fills with mass until gravitationally unstable
  - Next, spiral forms in disk efficiently transporting mass inward
  - Accretion takes place in short energetic bursts and long quiescent intervening periods
- Observations of knots/bullets in jets also suggestive …



[Vorobyov & Basu 2005, ApJ]



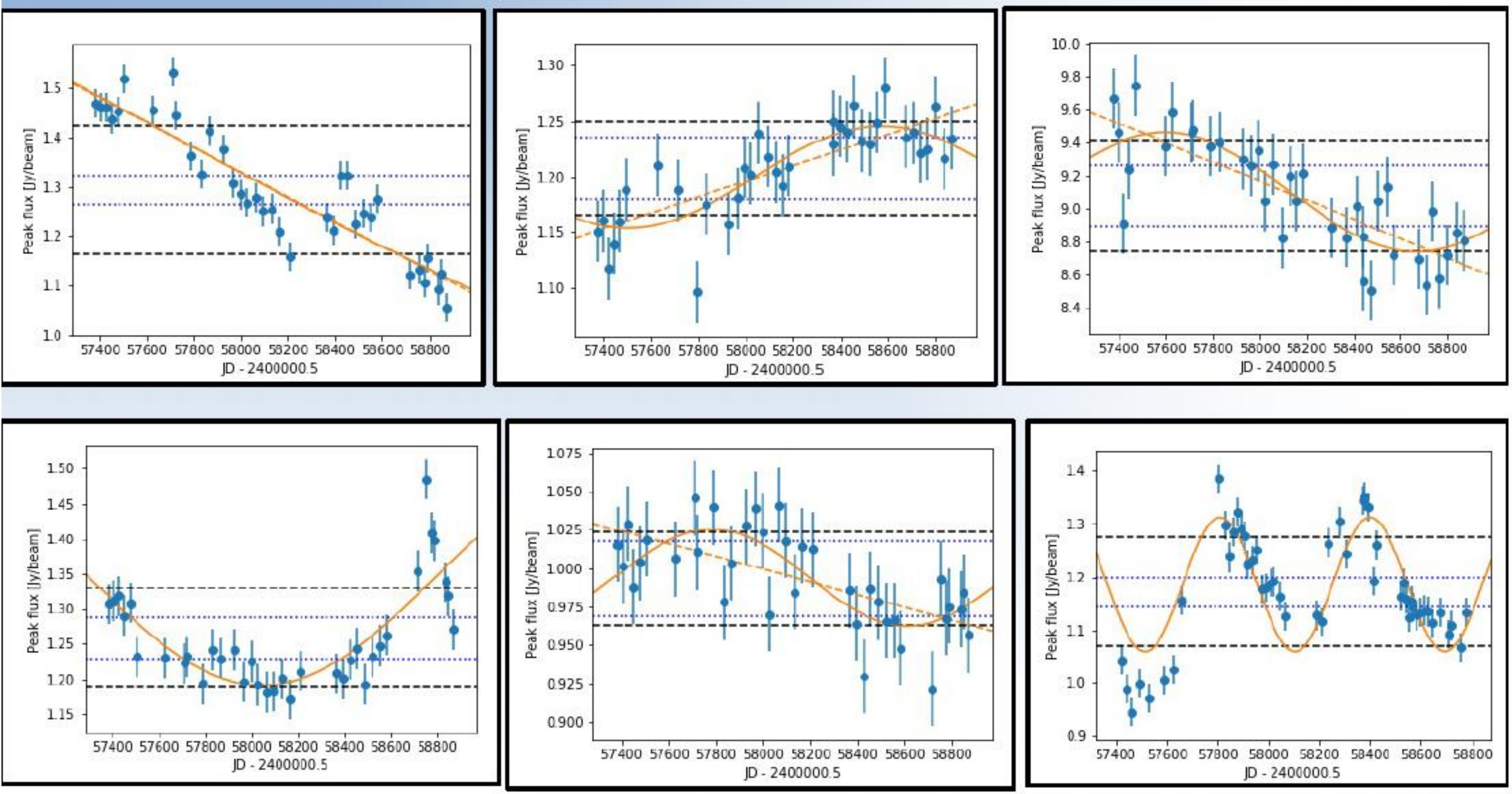


HH212

Doug Johnstone on JCMT Transient Survey talk on collaboration with M2O March 16, 2021

Bright Source Secular Variability: 50 months

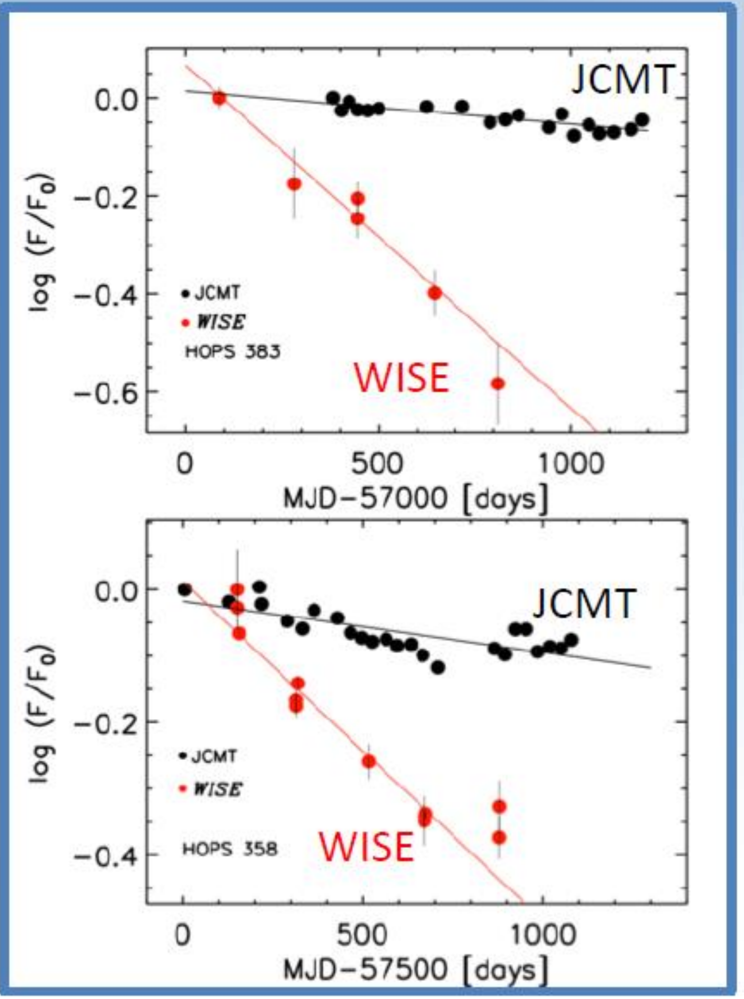
Apply ***sinusoids or linear fits*** to light curves; determine *'robust'* fits.



Doug Johnstone on JCMT Transient Survey
talk on collaboration with M2O March 16, 2021

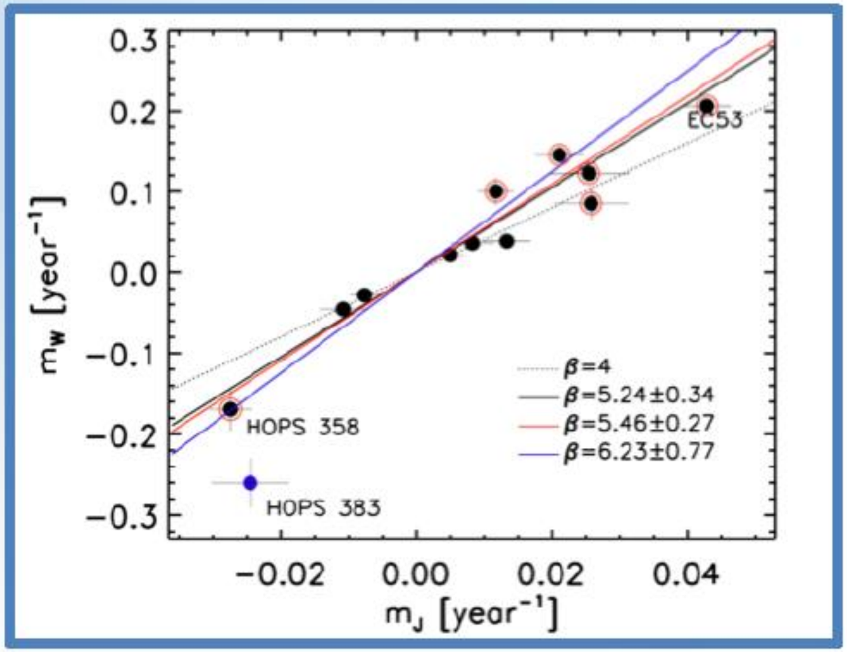
Spectral Energy Distribution Redux

Careful comparison between WISE/NeoWISE 4.6micron light curves and JCMT 850 micron light curves for 50 sources ***(12 clear variables!!)***



$F(\text{submm}) \propto T_{dust}$

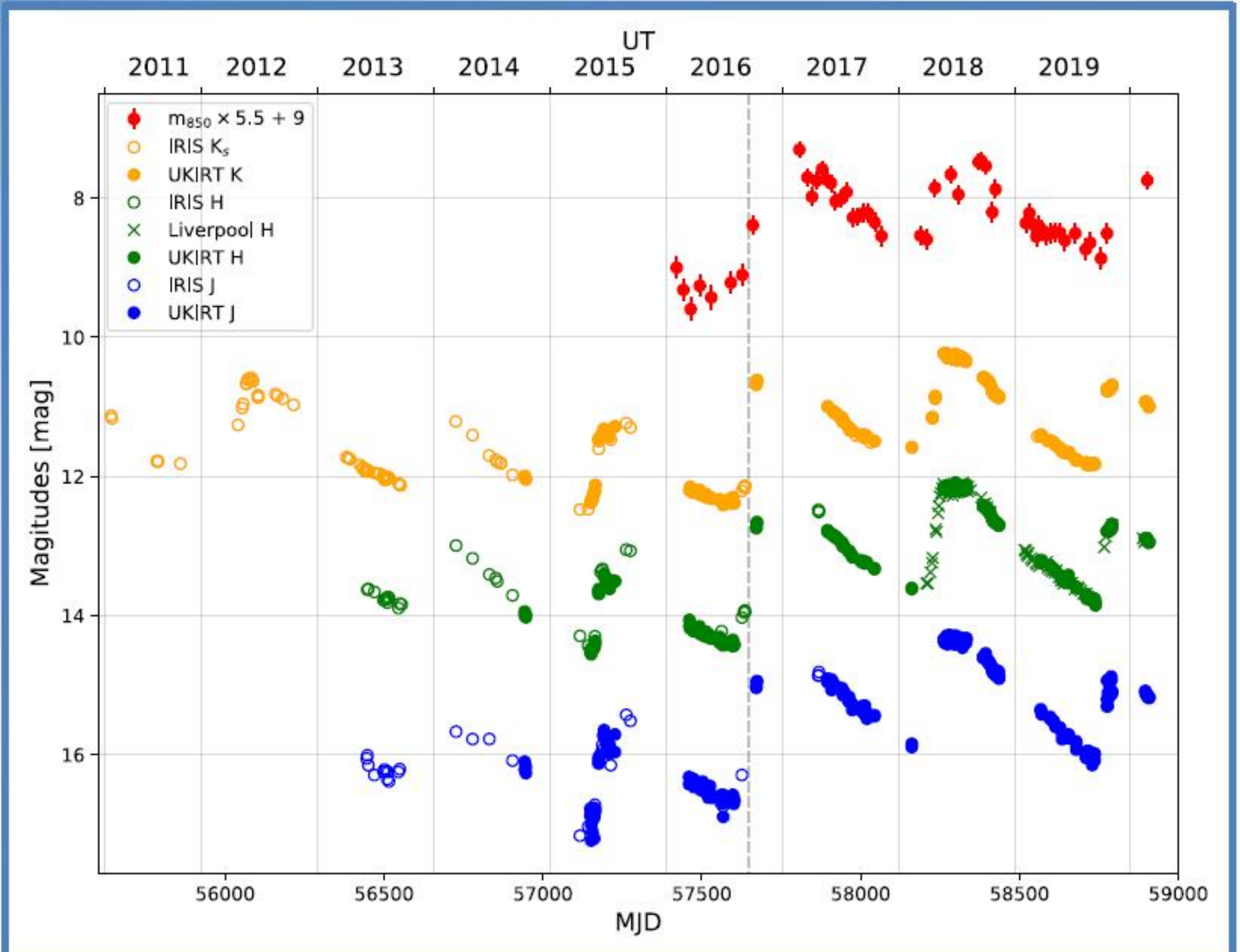
$F(\text{IR}) \propto L_{acc}$



UK Post-Doc Carlos Contreras Pena: [Contreras Pena+ 2020, MNRAS]

Doug Johnstone on JCMT Transient Survey talk on collaboration with M2O March 16, 2021

EC 53 – Analysis over multiple cycles



Submm

***K*-band**

***H*-band**

***J*-band**

[Lee+ 2020, ApJ]

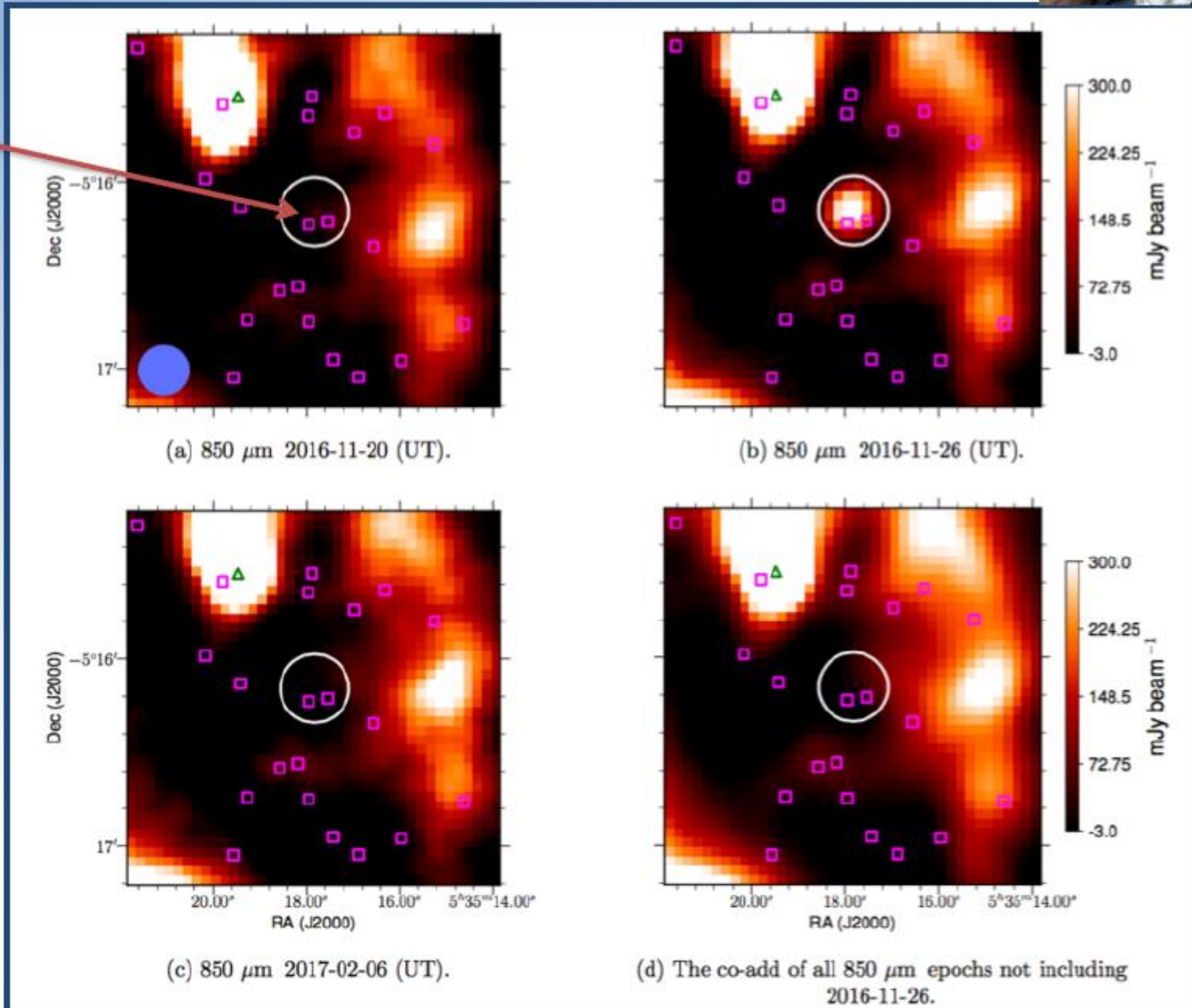
Doug Johnstone on JCMT Transient Survey talk on collaboration with M2O March 16, 2021

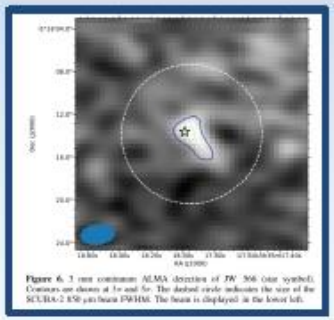
A Truly Transient Event

Searching for sources that appear in ***only one*** epoch:

Now Senior Scientist at EAO: Steve Mairs.

Location of
T Tauri binary star
JW 566 in the
Orion Integral
Shaped Filament





JW566 ALMA
3mm Map
Faint Disk Emission

[Mairs+ 2019, ApJ]

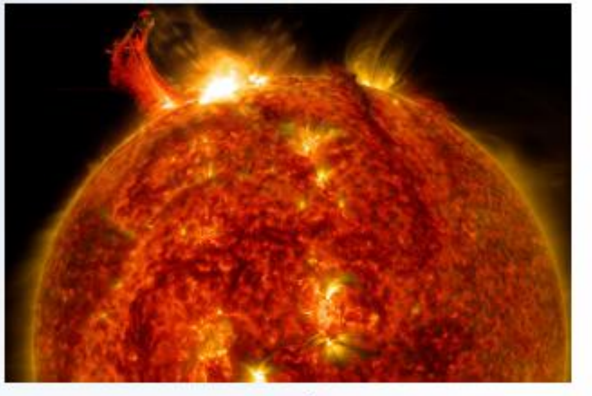
Doug Johnstone on JCMT Transient Survey
talk on collaboration with M2O March 16, 2021

A Truly Transient Event

Searching for sources that appear in ***only one*** epoch:

Now Senior Astronomer at EAO: Steve Mairs.

- JW 566 is a binary T Tauri Star in the Orion Molecular Cloud
  - K7 + M1.5 separation 0.86" (~350 AU)
- Visible at both 850 and 450 microns in only one (out of 20) epochs
  - ***First*** such transient event observed in the sub-mm
- Peak radio luminosity of ~10^{20} erg/s/Hz (~3×10^{31} erg/s = 0.01 Lsun)
  - ***10^{10} x brighter*** than typical **Solar flares** (if follows the Lx/Lr relation)
- Faded 50% in half an hour of observing
  - Suggests a size smaller than ~3 AU
- Estimated brightness temperature > 6×10^4 K
  - If size ~R_* then $T_b > 10^9$ K



Interpret this outburst to be a magnetic reconnection event that energized charged particles to emit synchrotron radiation.

[Mairs+ 2019, ApJ]

What's Next for Protostar Variability?

JCMT Transient

- Continues for another 3 more years (*added 6 more distant, intermediate mass regions*)
- Calibration and analysis of 450 micron data – **UVic UG Colton Broughton**
- Structure Function Analysis of light curves (c.f. AGN) – **UVic UG Spencer Plovie**

FYST (CCAT-Prime) Survey Telescope

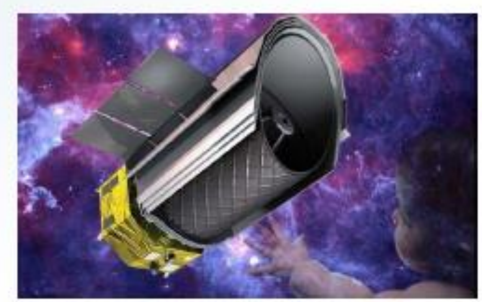
- Higher sensitivity, higher frequency (optimal at 350 microns), larger field
- 2019 *HAA/NRC New Beginnings Project* to design 350 micron camera
- Analysing efficient/effective scanning modes – **UVic UG Kaela Douglas**

ALMA/ACA Monitoring/Follow-up

- Seven ACA epochs monitoring sources in Serpens – **UVic PhD Logan Francis**
  - Important test of default ALMA calibration and improvement methods

Preparing for Future Far IR Space Telescopes (SPICA/ORIGINS)

- Excellent calibration opportunity, limited lifetime
- Better suited for follow-up of ground-based monitoring?

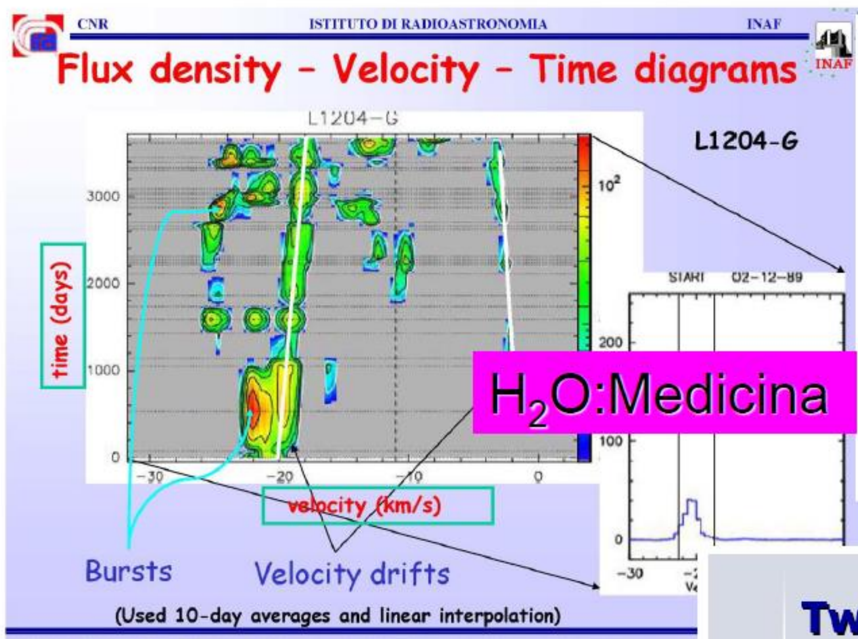


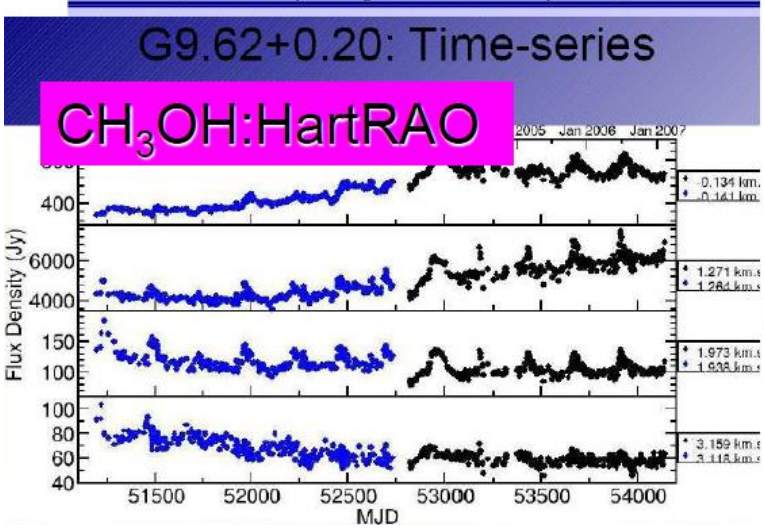
SOFIA

- Not particularly well suited for monitoring, but follow-up …

Doug Johnstone on JCMT Transient Survey talk on collaboration with M2O March 16, 2021

Selected targets: list of individual sources monitored with some chosen cadence



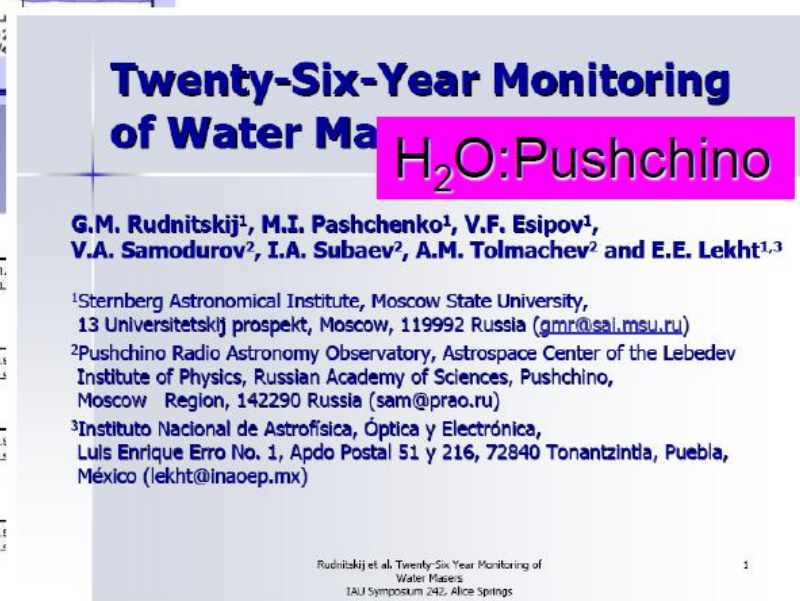


Monotonic changes

Flares

Periodic changes

Velocity drifts



Twenty-Six-Year Monitoring of Water Ma

G.M. Rudnitskij[1], M.I. Pashchenko[1], V.F. Esipov[1], V.A. Samodurov[2], I.A. Subaev[2], A.M. Tolmachev[2] and E.E. Lekht[1,3]

[1]Sternberg Astronomical Institute, Moscow State University, 13 Universitetskij prospekt, Moscow, 119992 Russia (gmr@sai.msu.ru)

[2]Pushchino Radio Astronomy Observatory, Astrospace Center of the Lebedev Institute of Physics, Russian Academy of Sciences, Pushchino, Moscow Region, 142290 Russia (sam@prao.ru)

[3]Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro No. 1, Apdo Postal 51 y 216, 72840 Tonantzintla, Puebla, México (lekht@inaoep.mx)

Rudnitskij et al. Twenty-Six Year Monitoring of Water Masers
IAU Symposium 242, Alice Springs

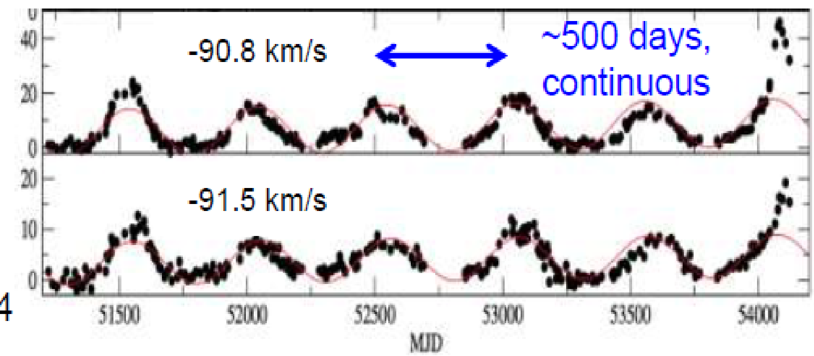
- Parfenov S.Yu., Sobolev A.M. 2014, MNRAS, 444, 620
  “On the Class II methanol maser periodic variability due to the rotating spiral shocks in the gaps of discs around young binary stars“
- Sanna A., Moscadelli L., Surcis G. et al. 2017, A&A, 603, A94
  “Planar infall of CH_3OH gas around Cepheus A HW2”
- Zinchenko I., Liu S.-Y., Su Y.-N., Sobolev A.M. 2017, A&A, 606, 6
  “Detection of a new methanol maser line with ALMA”
- Meyer D.M.-A., Vorobyov E.I., Elbakyan V.G. et al. 2019, MNRAS, 482, 5459
  “Burst occurrence in young massive stellar objects”
- Brogan C.L., Hunter T.R., Towner A.P.M. et al. 2019, ApJL, 881, L39
  “Sub-arcsecond (Sub)millimeter Imaging of the Massive Protocluster G358.93-0.03: Discovery of 14 New Methanol Maser Lines Associated with a Hot Core”
- Burns R.A., Sugiyama K., Hirota T. et al. 2020, Nature Astronomy, 4, 506
  “A heatwave of accretion energy traced by masers in the G358-MM1 high-mass protostar”
- Chen Xi, Sobolev A.M., Breen S.L. et al. 2020, ApJL, 876, 22C
  “$^{13}CH_3OH$ Masers Associated With a Transient Phenomenon in a High-mass Young Stellar Object”
- Chen Xi, Sobolev A.M., Ren Z.-Y. et al. 2020, Nature Astronomy, 4, 1170
  “New maser species tracing spiral-arm accretion flows in a high-mass young stellar object”
- Ladeyschikov D.A., Urquhart J.S., Sobolev A.M., Breen S.L., Bayandina O.S. 2020, AJ, 160, 213
  “The Physical Parameters of Clumps Associated with Class I Methanol Masers”
- Stecklum B., Wolf V., Linz H. et al. 2021, A&A, 646, 161
  “Infrared observations of the flaring maser source G358.93-0.03. SOFIA confirms an accretion burst from a massive young stellar object”

Sugiyama IAUS 336, 2017

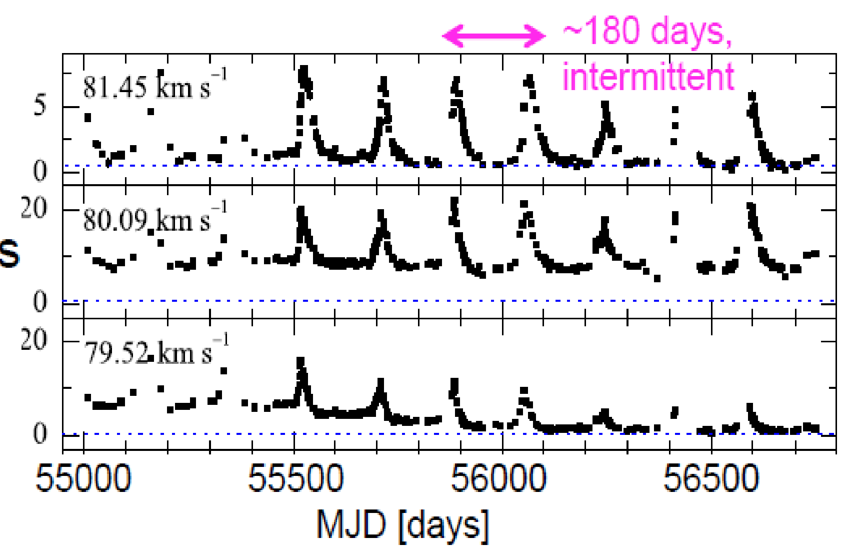
Periodic flux variation around HMPSs

Discovered in G 9.62+0.20E of 6.7/12.2 GHz methanol masers with a period of 246 d (Goedhart+ 03)

- So far, 20 sources (e.g., Goedhart+ 04
- Periods : ~30–670 d
- Pattern : Continuous/Intermittent
- Synchronized in multi-spectral components
- Synchronized with other masers (Araya+10; Green+ 12; Szymczak+ 16)



G 331.13-00.24: Continuous (Goedhart+ 07)



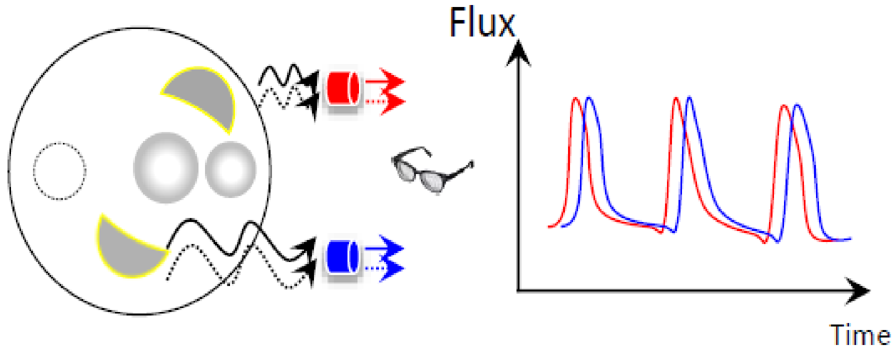
G 22.357+0.066: Intermittent (Szymczak+15)

Possibly caused by central system in tiny spatial scales of ~**0.1-1 au** (expected from Keplerian rotation)

Candidates to cause periodicity

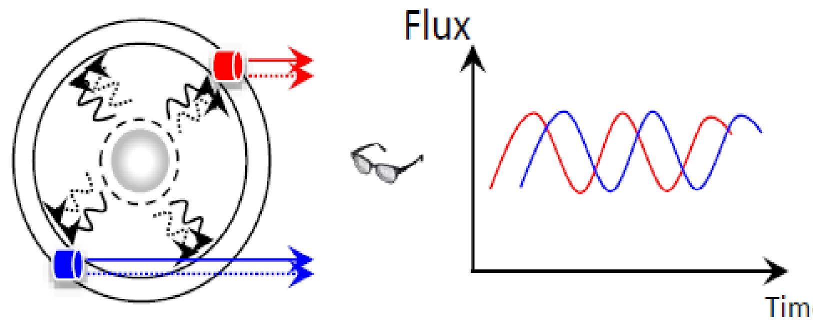
- Colliding wind binary
  (van der Walt+ 09; van der Walt 11)
- Stellar pulsation instability
  (Inayoshi+ 13; Sanna+ 15)
- Spiral shock heating in a circum-binary disk (Parfenov & Sobolev 14)

Seed photon; Intermittent



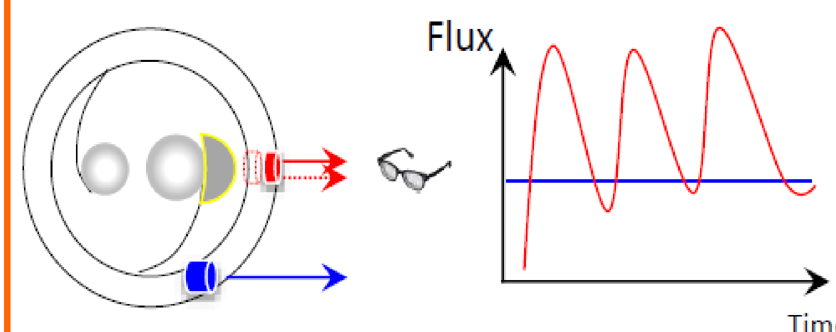
Colliding wind binary

Dust temperature; Continuous



Stellar pulsation instability

Classification by van der Walt+ (16)



Spiral shock heating in circumbinary disk

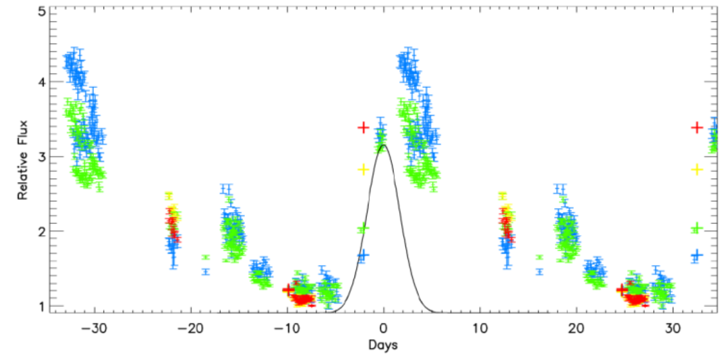
Triggered monitoring

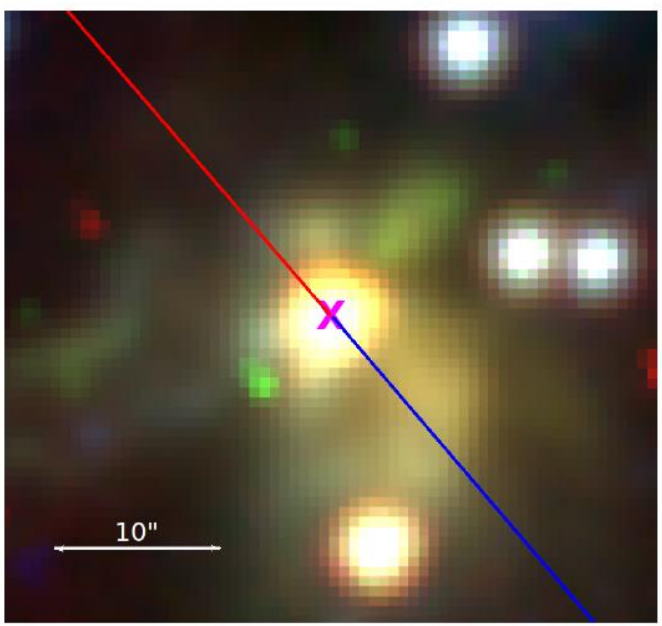
G107.30+5.64

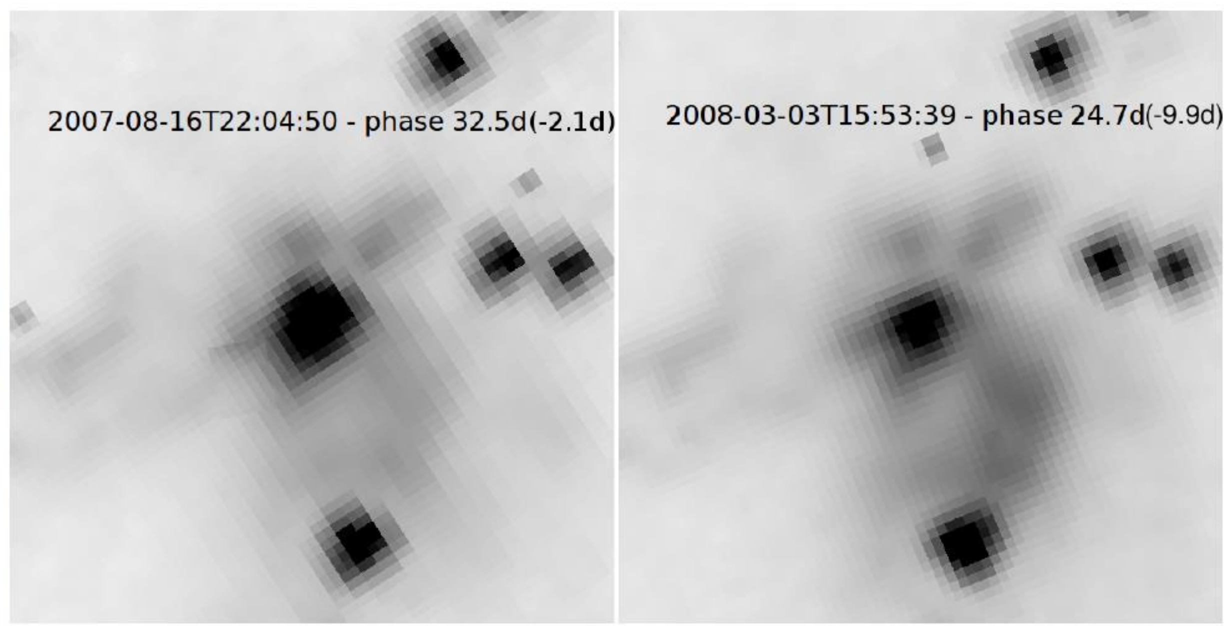
Infrared variability, maser activity, and accretion of massive young stellar objects

Bringfried Stecklum[1], Alessio Caratti o Garatti[2], Klaus Hodapp[3], Hendrik Linz[4], Luca Moscadelli[5], and Alberto Sanna[6]

IAUS336)

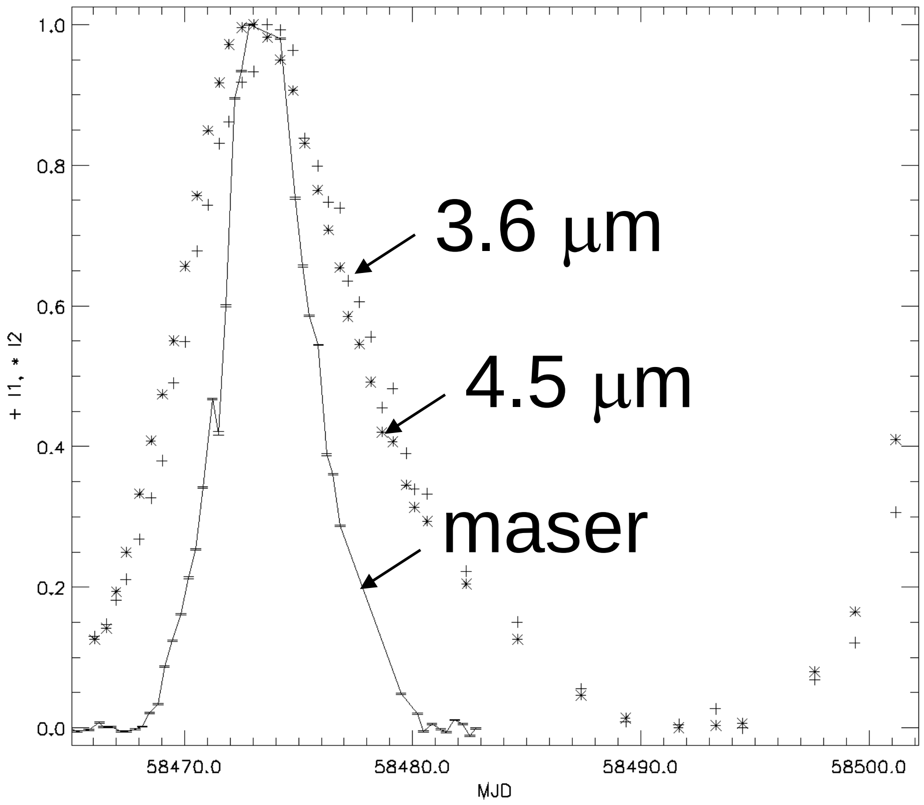


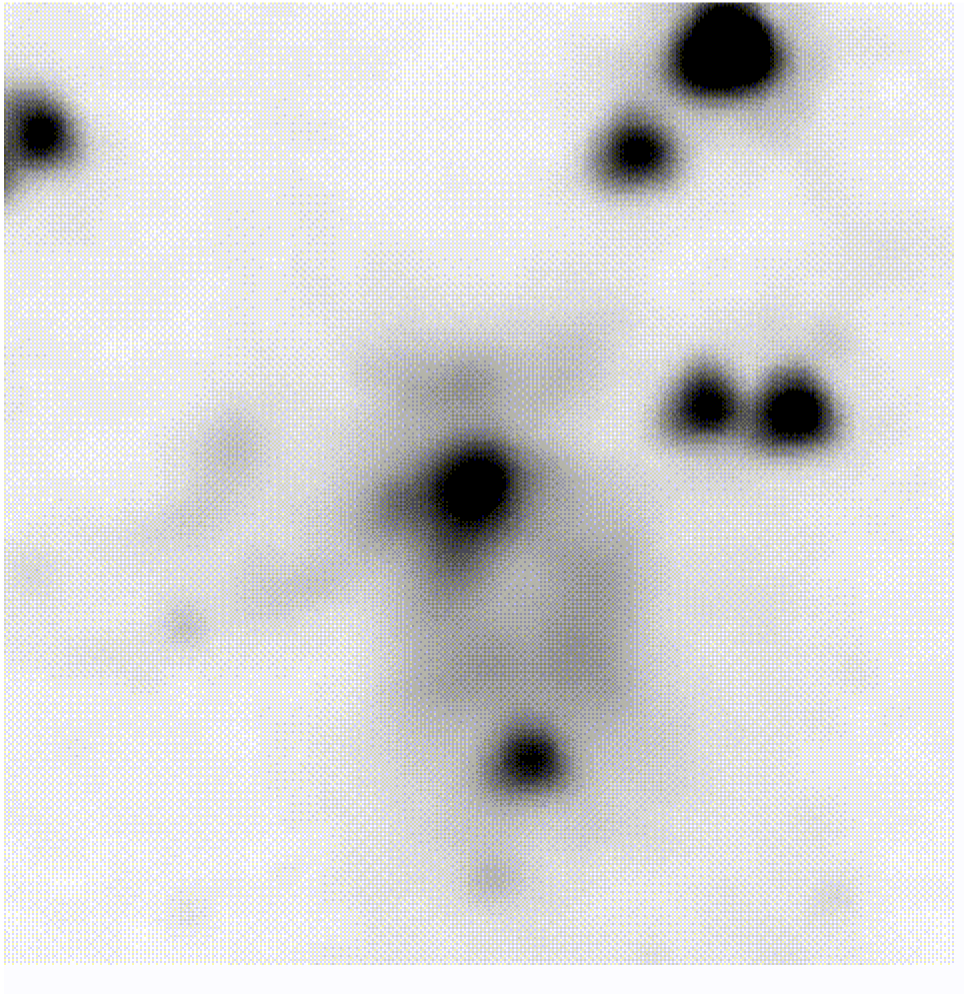




Stecklum et al. A&A, in prep.

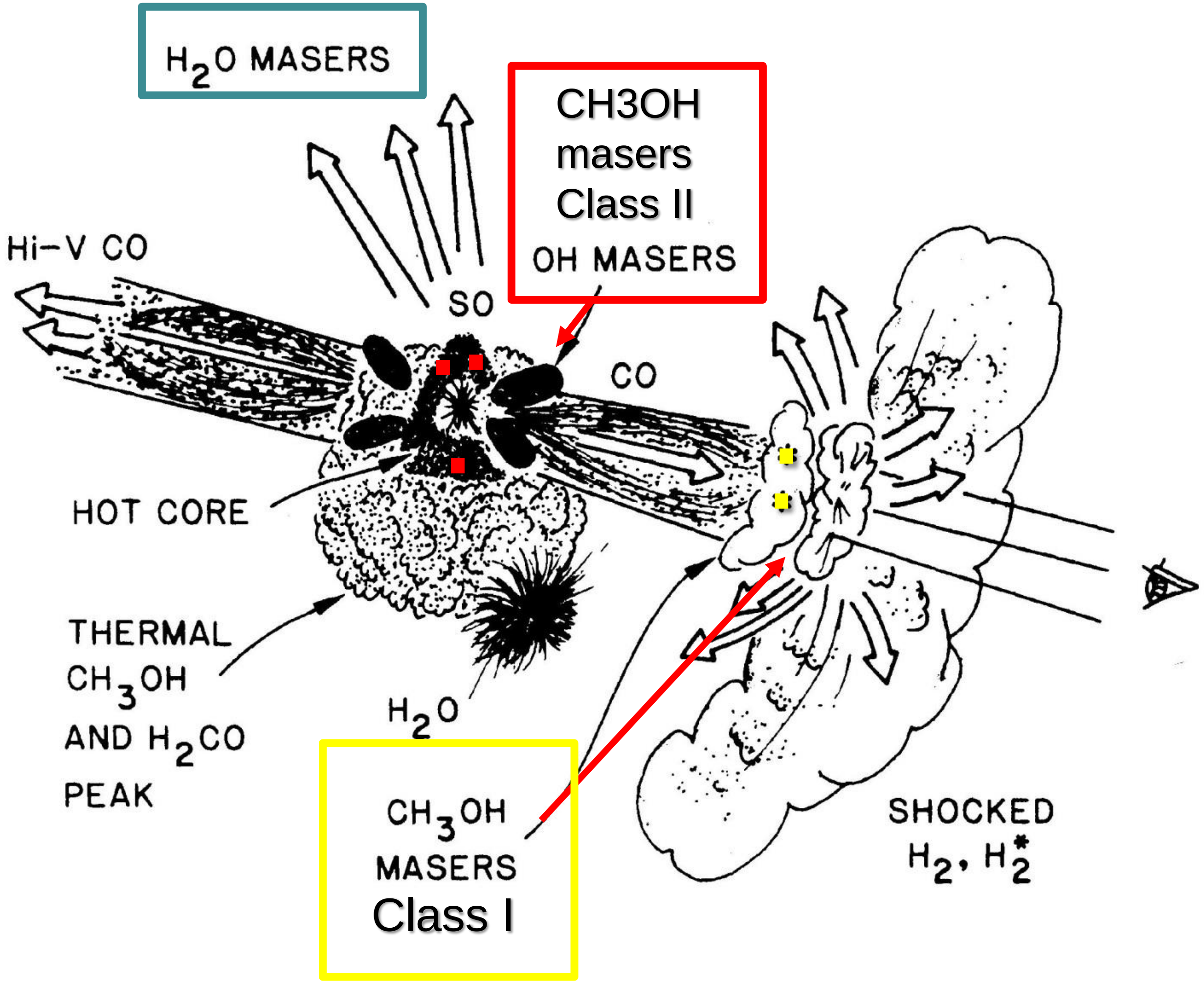
Spitzer
3.6 μm, 4.5 μm
Torun 32m, Irbene 16m
6.7 GHz maser





G107.30+5.64

Masers in vicinity of massive YSOs

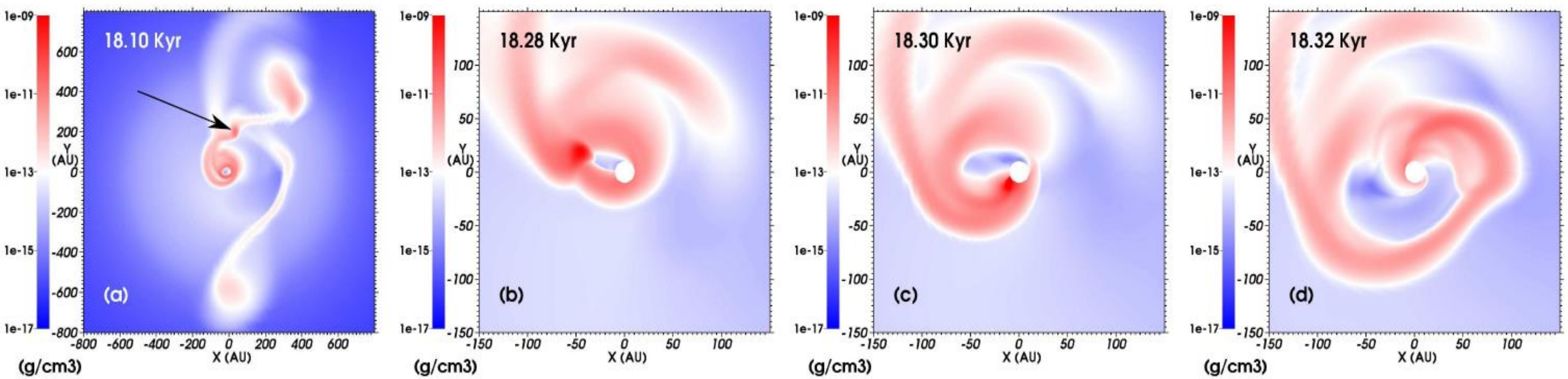


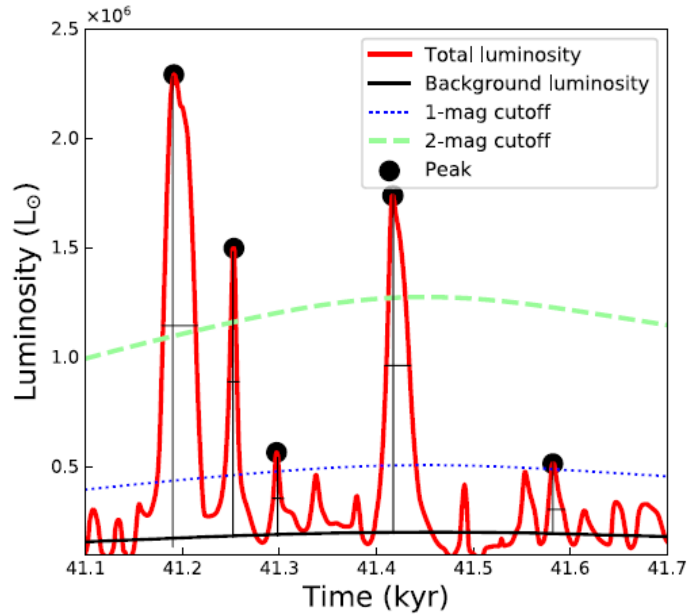
Modified picture from [Johnston et al. (1992ApJ...385..232J)]

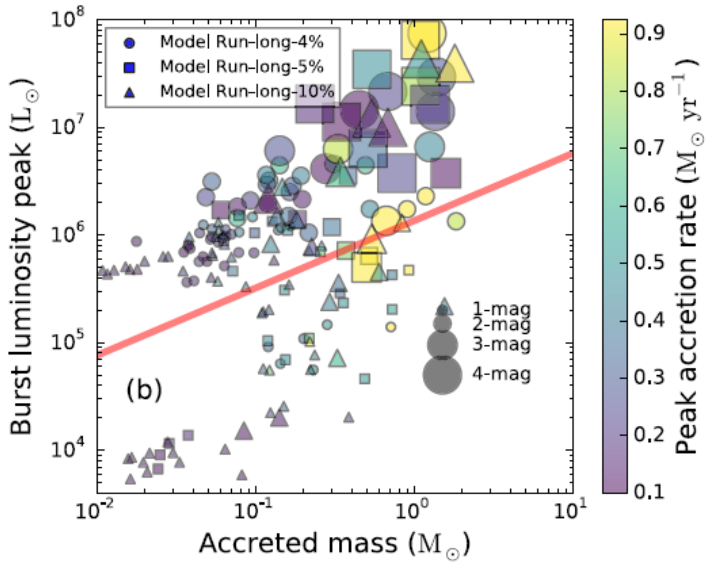
MNRAS **464,** L90–L94 (2017)
Advance Access publication 2016 September 15
doi:10.1093/mnrasl/slw187

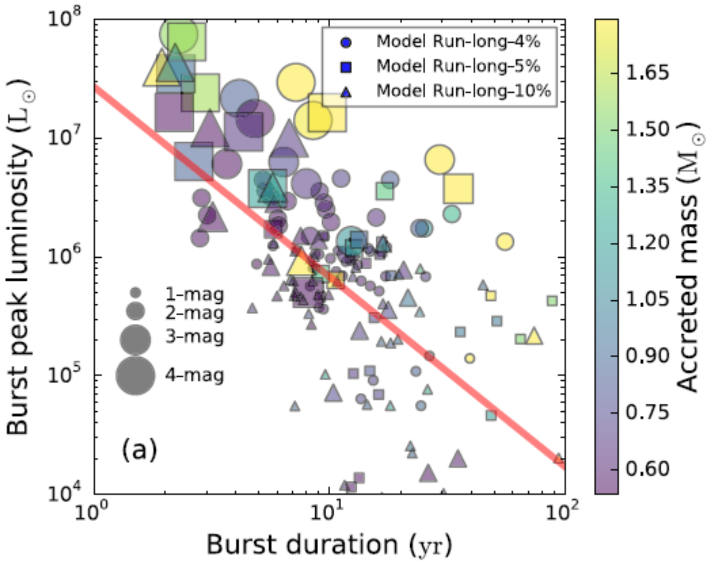
On the existence of accretion-driven bursts in massive star formation

D. M.-A. Meyer,[1★] E. I. Vorobyov,[2,3] R. Kuiper[1] and W. Kley[1]







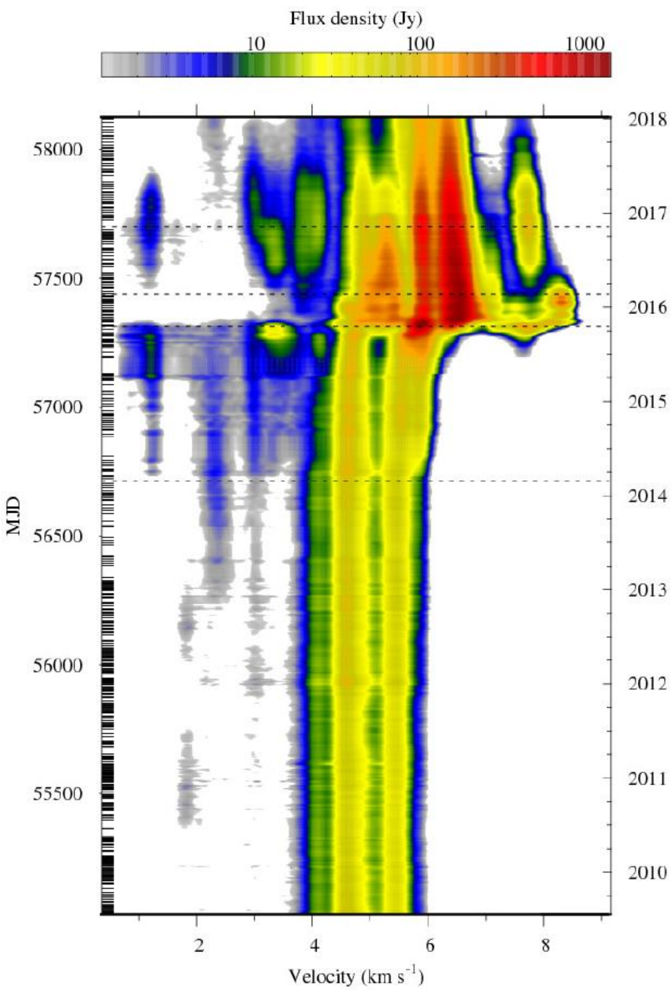


Burst occurrence in young massive stellar objects

D. M.-A. Meyer,[1★] E. I. Vorobyov,[2,3] V. G. Elbakyan,[3] B. Stecklum,[4] J. Eislöffel[4] and A. M. Sobolev[5]

MNRAS **482,** 5459–5476 (2019)

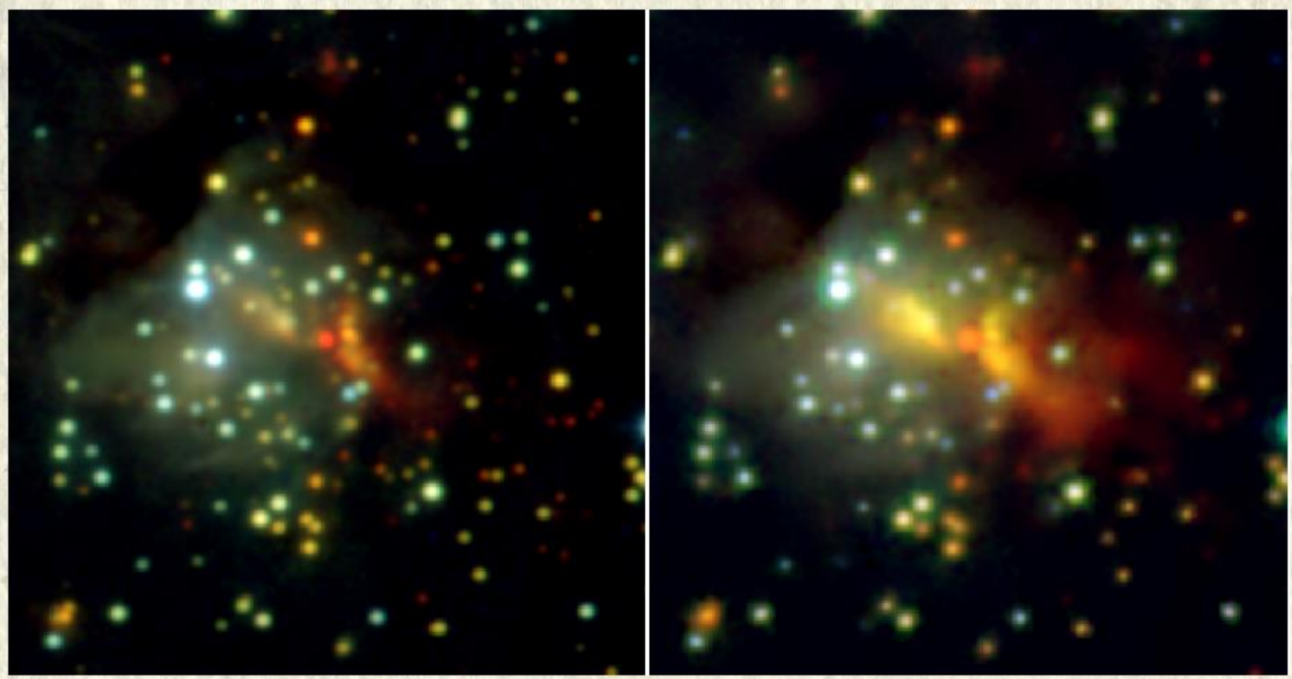
S255IR-NIRS3 flare



nature physics
LETTERS
PUBLISHED ONLINE: 14 NOVEMBER 2016 | DOI: 10.1038/NPHYS3942

Disk-mediated accretion burst in a high-mass young stellar object

A. Caratti o Garatti[1*], B. Stecklum[2], R. Garcia Lopez[1], J. Eislöffel[2], T. P. Ray[1], A. Sanna[3], R. Cesaroni[4], C. M. Walmsley[1,4], R. D. Oudmaijer[5], W. J. de Wit[6], L. Moscadelli[4], J. Greiner[7], A. Krabbe[8], C. Fischer[8], R. Klein[9] and J. M. Ibañez[10]



S255IR-NIRS3 – the first HMYSO accretion burst (Stecklum+ 2016, Caratti o Garatti+ 2016)

Giant burst of methanol maser in S255IR-NIRS3

M. Szymczak[1], M. Olech[1], P. Wolak[1], E. Gérard[2], and A. Bartkiewicz[1]

A&A 617, id.A80, 2018

Infrared variability, maser activity, and accretion of massive young stellar objects

Bringfried Stecklum[1], Alessio Caratti o Garatti[2], Klaus Hodapp[3], Hendrik Linz[4], Luca Moscadelli[5], and Alberto Sanna[6]

Proceedings IAU Symposium No. 336, 2017
A. Tarchi, M.J. Reid & P. Castangia, eds.

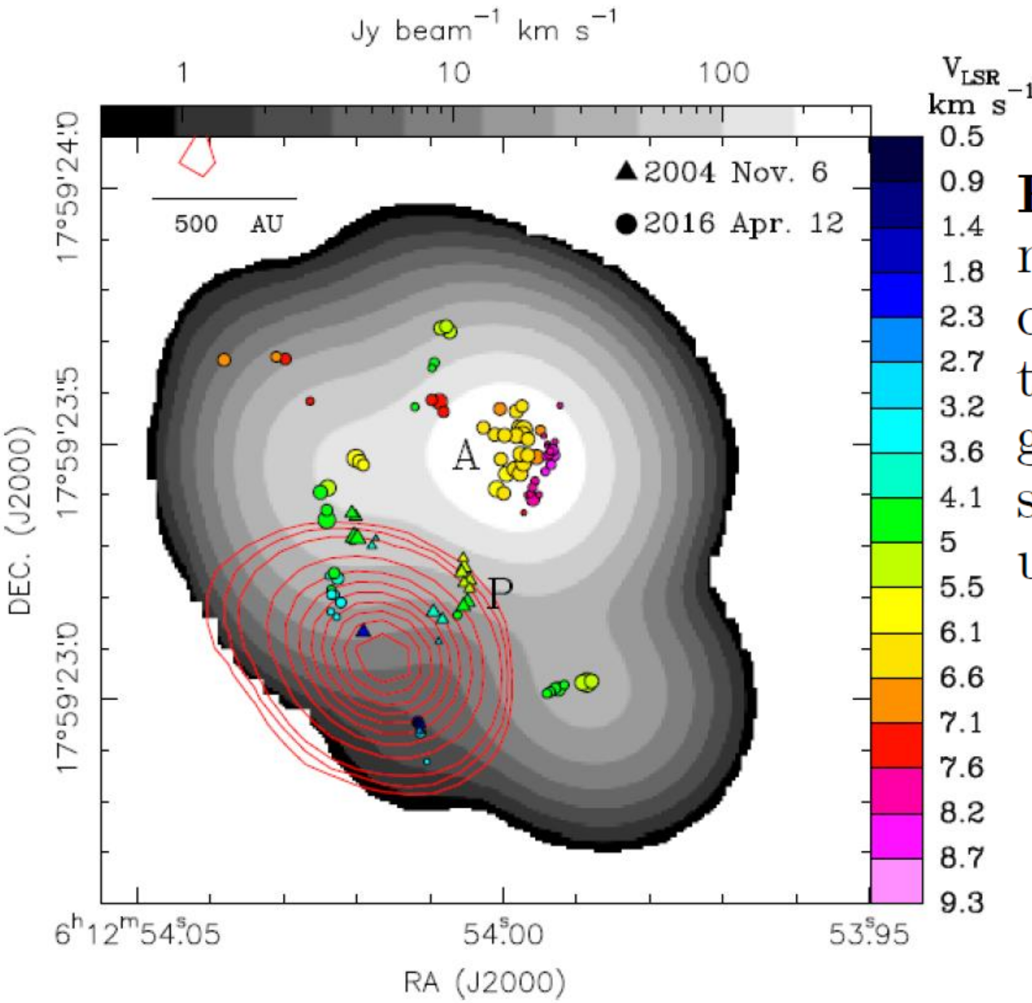


Figure 1. Map of the 6.7 GHz methanol masers toward NIRS3. Triangles and circles represent maser spots before and after the burst, respectively. The velocity-integrated emission of the 6.7 GHz masers (gray scale) and the JVLA 5 GHz radio continuum emission (red contours) are also shown.

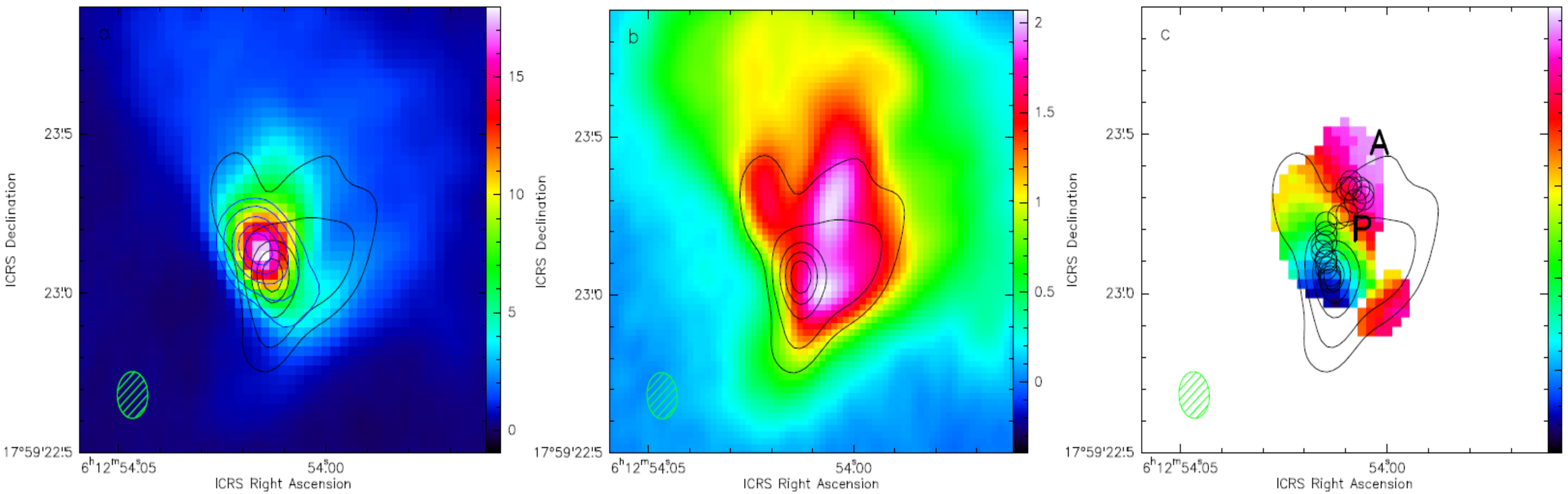
A&A 606, L6 (2017)
DOI: 10.1051/0004-6361/201731752

Astronomy & Astrophysics

Letter to the Editor

Detection of a new methanol maser line with ALMA

I. Zinchenko[1], S.-Y. Liu[2], Y.-N. Su[2], and A. M. Sobolev[3]

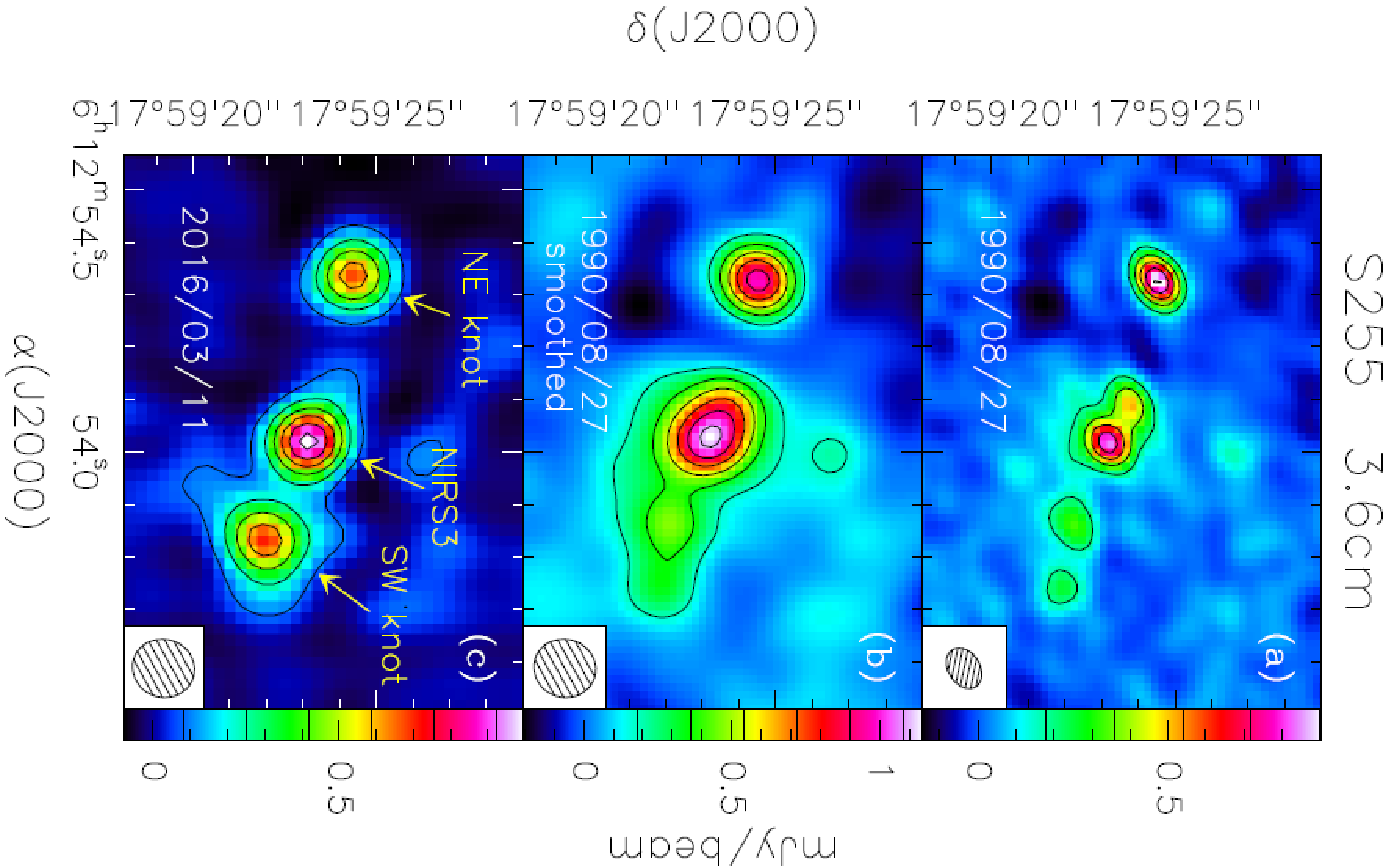


CH_3OH 14_1-14_0 A^{-+} transition at 349.1 GHz

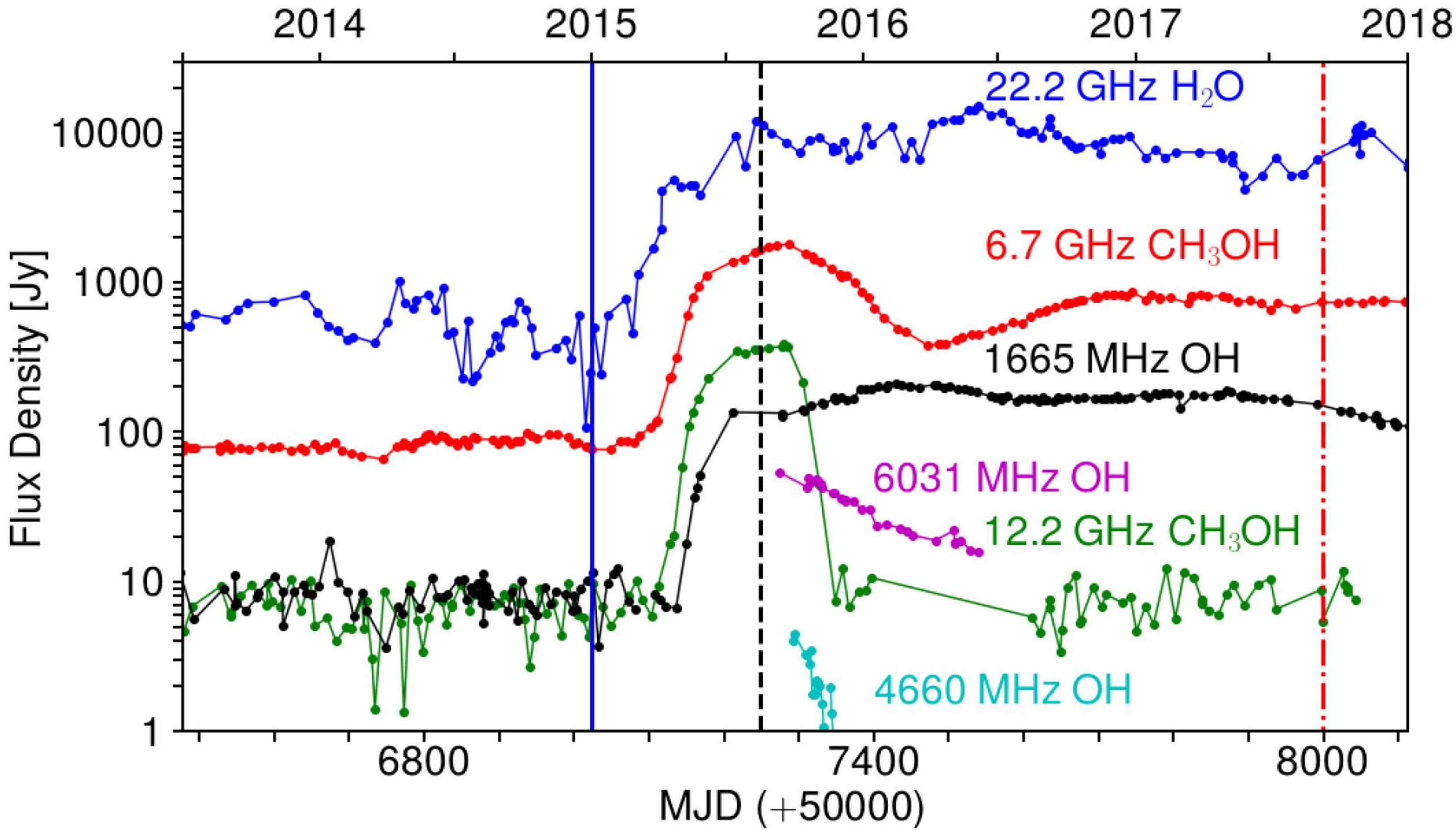
Radio outburst from a massive (proto)star ⋆

When accretion turns into ejection

R. Cesaroni[1], L. Moscadelli[1], R. Neri[2], A. Sanna[3], A. Caratti o Garatti[4], J. Eislöffel[5], B. Stecklum[5], T. Ray[4], and C. M. Walmsley⋆⋆



NGC 6334 I – MM1 flare

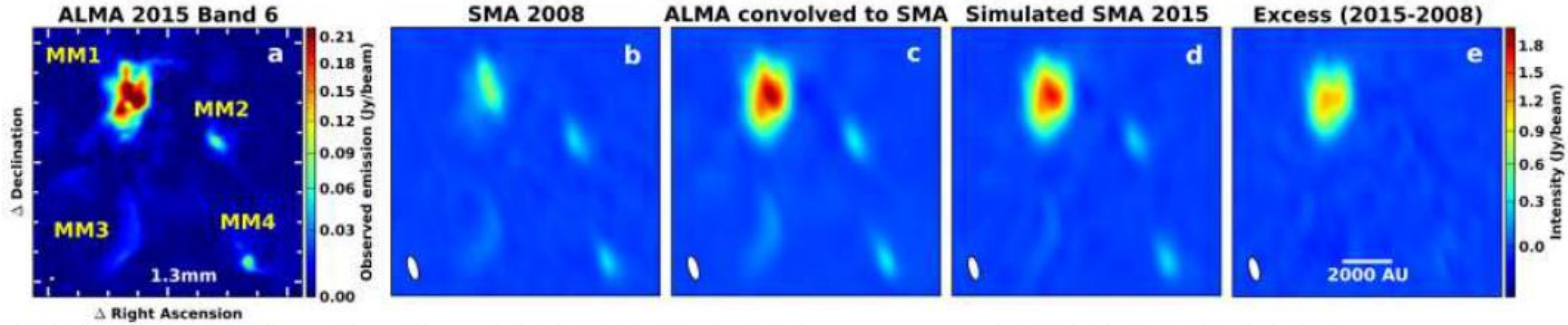


A Masing Event in NGC 6334I: Contemporaneous Flaring of Hydroxyl, Methanol and Water Masers

G. C. MacLeod[1⋆], D. P. Smits[2], S. Goedhart[3], T. R. Hunter[4], C. L. Brogan[4], J. O. Chibueze[3,5,6], S. P. van den Heever[1], C. J. Thesner[5], P. J. Banda[7], and J. D. Paulsen[8]

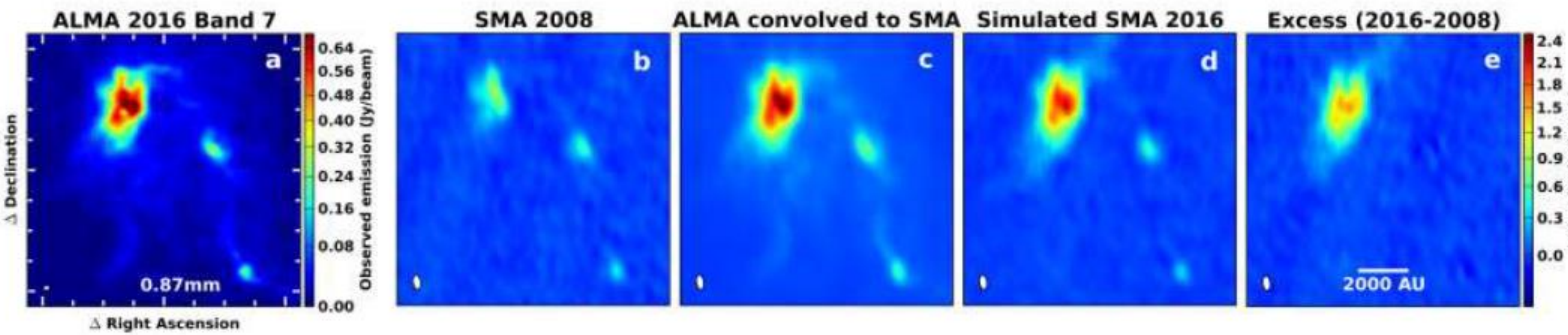
MNRAS 478, 1077, 2018

An extraordinary brightening in Band 6 & 7 (2008-2015)



MM1 Band 6 flux density: 2008.6 SMA: 2.34 Jy versus 2015.6 ALMA: 10.8 Jy

- Simulation: SMA could have recovered: 9.4 Jy
- Increase = factor of 3.9! No change in other 3 sources.



MM1 Band 7 flux density: Increase = 21 Jy = factor of 4.2. No fading over a year.

- Spectral index of excess is 2.6 – confirms it is dust

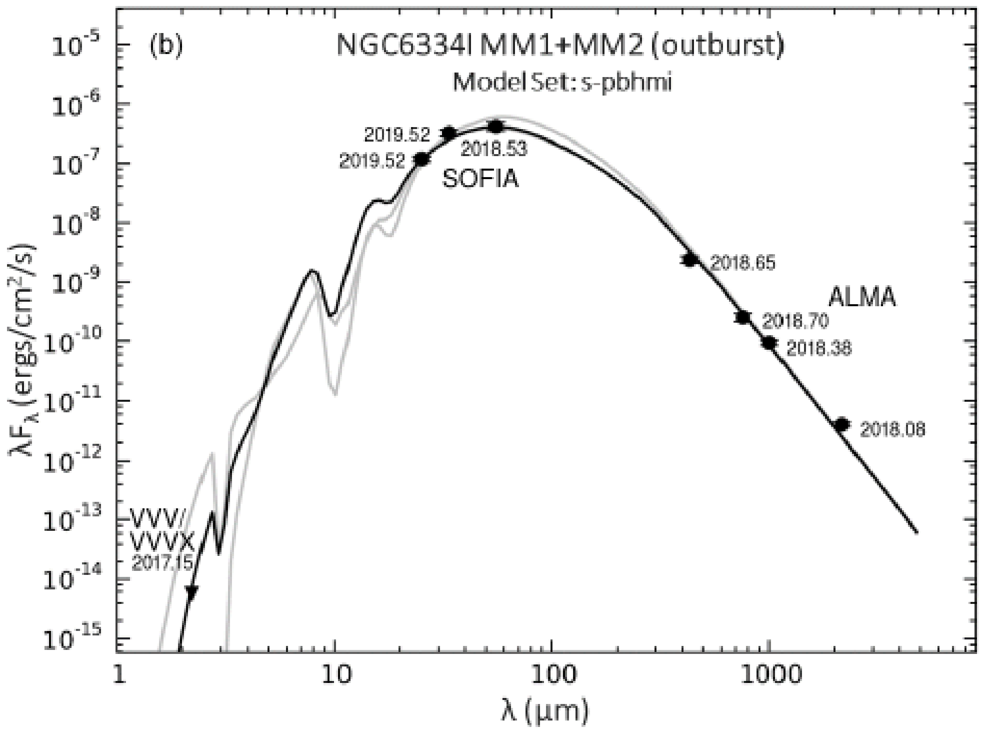
Hunter, Brogan+ 2017 ApJL

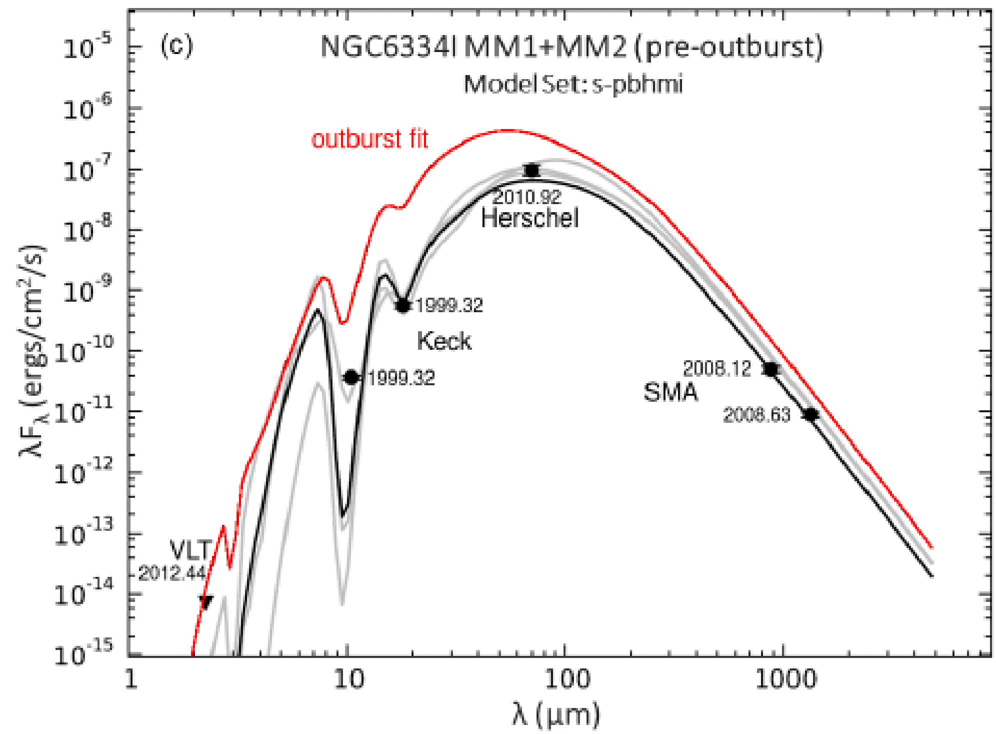
from presentation of Hunter at IAUS 336

arXiv:2104.05187v1 [astro-ph.GA] 12 Apr 2021

The Extraordinary Outburst in the Massive Protostellar System NGC 6334 I-MM1: Strong Increase in Mid-Infrared Continuum Emission

T. R. Hunter,[1,2] C. L. Brogan,[1] J. M. De Buizer,[3] A. P. M. Towner,[4] C. D. Dowell,[5] G. C. MacLeod,[6,7] B. Stecklum,[8] C. J. Cyganowski,[9] S. J. El-Abd,[10] and B. A. McGuire[11,1,2]



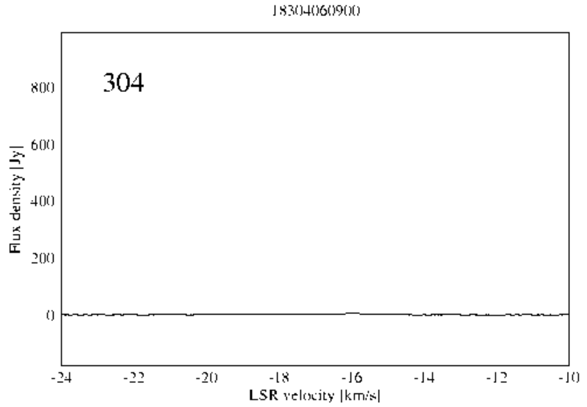


Maser Monitoring Organization (M2O)

(2017 IAUS336)

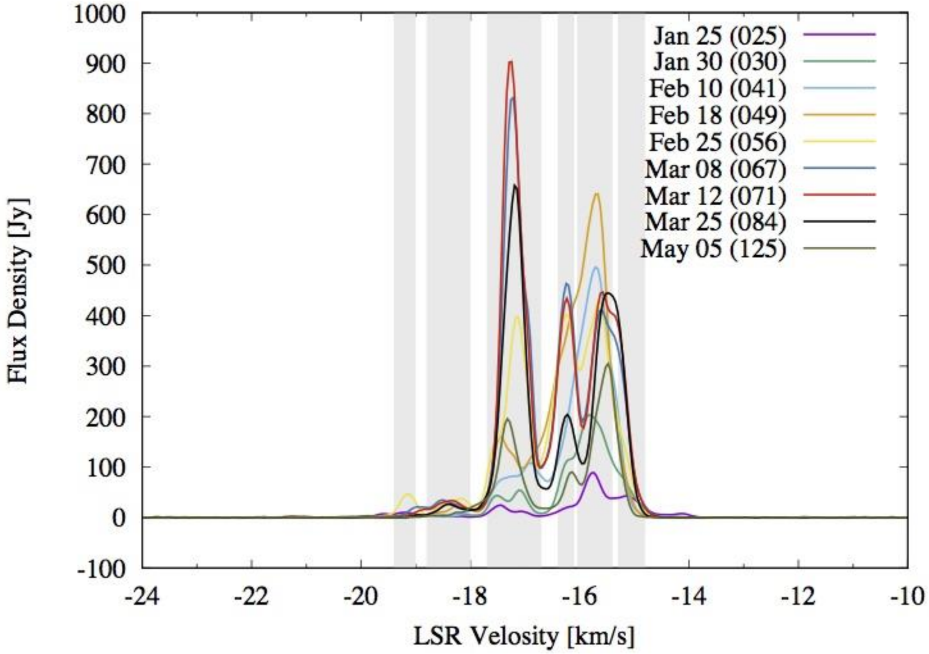
- **Formation of a network of MASER monitoring telescopes:**
  - **Independently, groups thought it useful to collaborate.**
  - **Expressed interest in formalisation of coordinated observing**
  - **Creation of a network of communications**
- **Functions:**
  - **Provide calibration and confirmation services to each**
  - **Create catalogue of interesting and monitored sources**
  - **Develop triggering methodologies**
  - **Operate as a 24 hour monitoring service when required**
  - **Inform other facilities of interesting phenomena**
  - **Provide fast follow-up observation services.**
- **Longer term**
  - **Provide multi-wavelength monitoring,**
    - **millimeter, optical/IR, etc.**
- **Countries represented:**

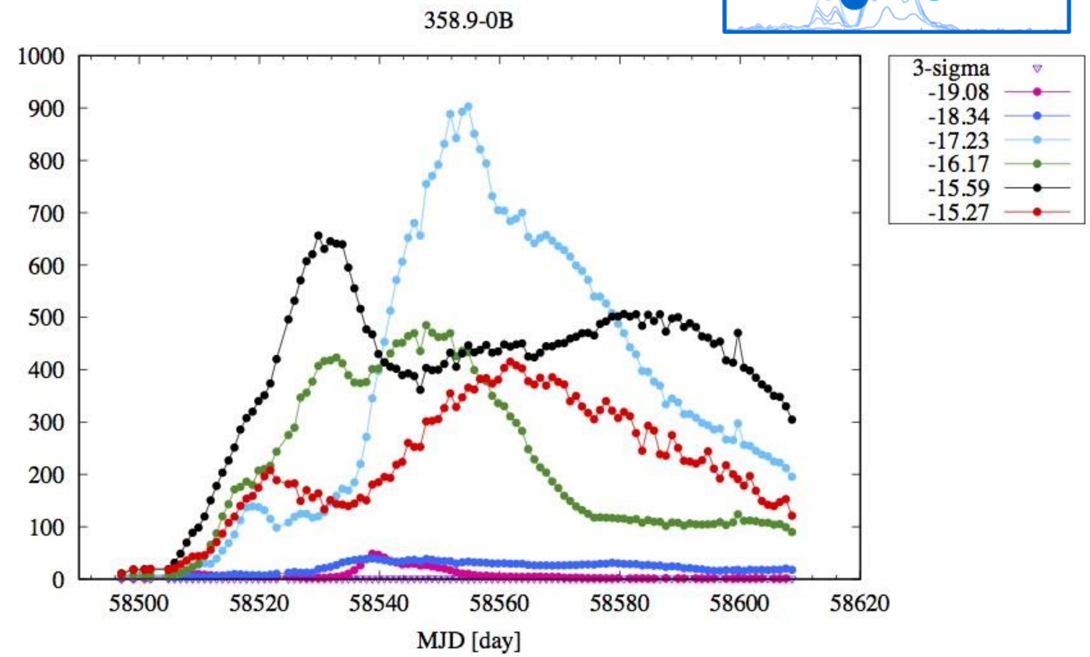
Australia, Canada, China, France, Germany, Italy, Japan, Korea, Latvia, Poland, Russia, South Africa, Thailand, USA



G358.931-0.030
March 2019

https://www.masermonitoring.com/





Sugiyama, Saito, Yonekura, Momose, Munetake

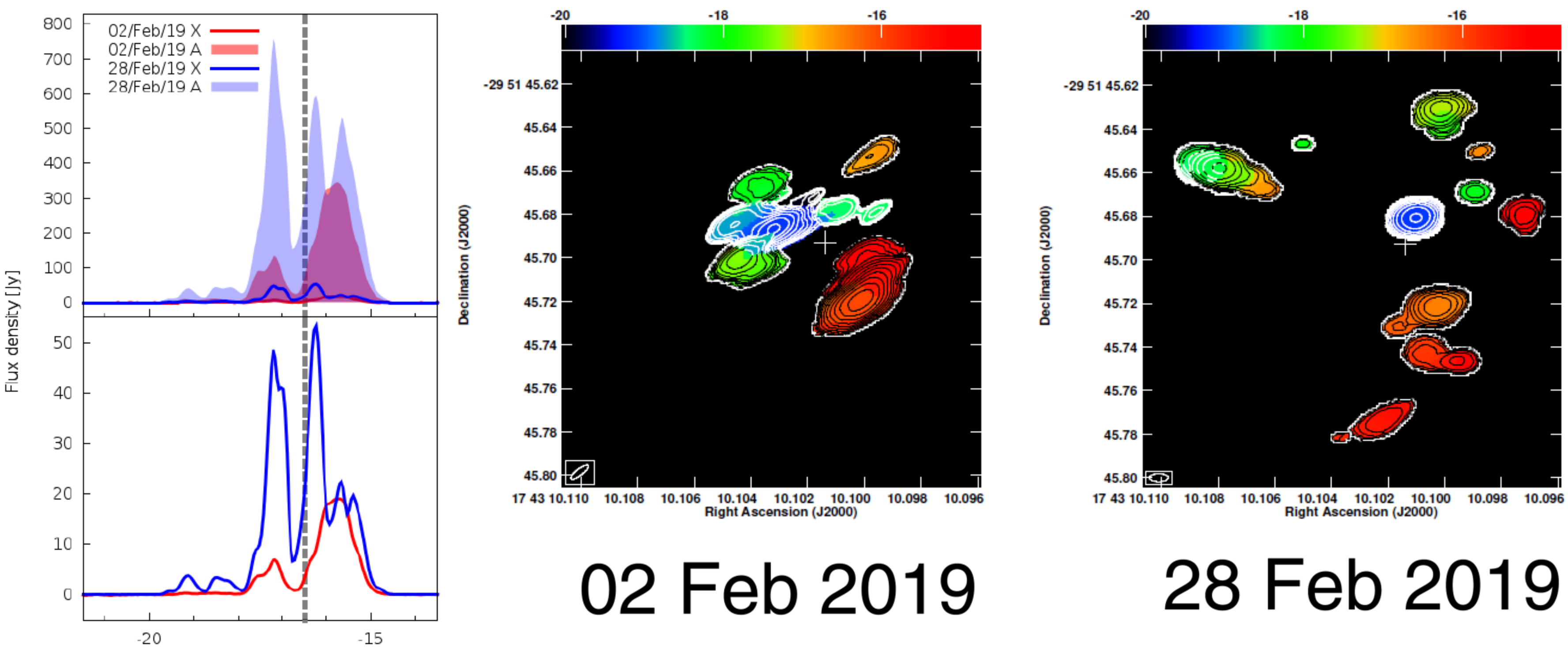
Bursting activity of the 6.668-GHz CH3OH maser detected in G 358.93-00.03 using the Hitachi 32-m

2019ATel12446....1S

2020, Nature Astronomy, 4, 506

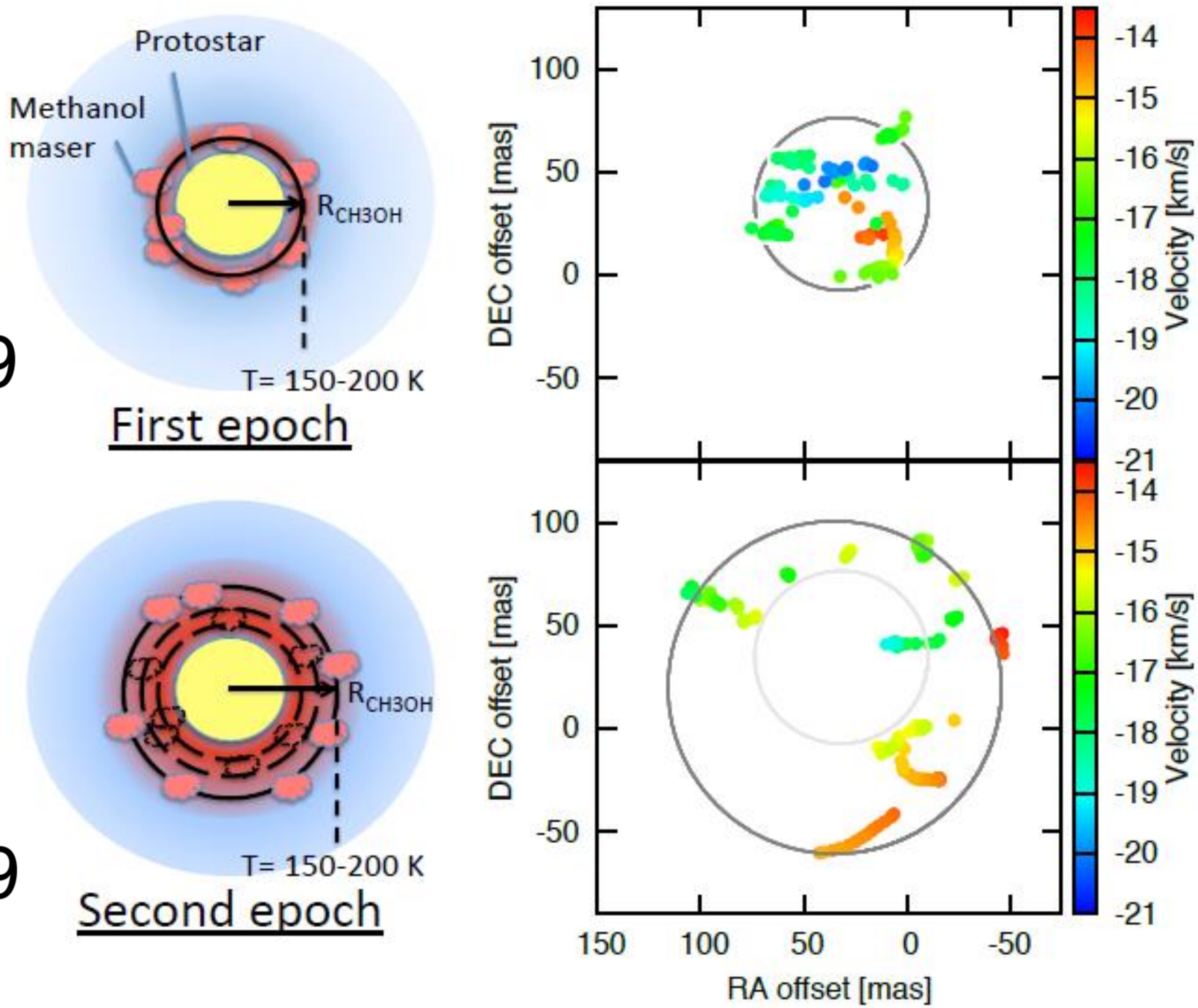
A heatwave of accretion energy traced by masers in the G358-MM1 high-mass protostar

R. A. Burns[1,2★], K. Sugiyama[1,3], T. Hirota[1], Kee-Tae Kim[2,4], A. M. Sobolev[5], B. Stecklum[6], G. C. MacLeod[7,8], Y. Yonekura[9], M. Olech[10], G. Orosz[11,12], S. P. Ellingsen[11], L. Hyland[11], A. Caratti o Garatti[13], C. Brogan[14], T. R. Hunter[14], C. Phillips[15], S. P. van den Heever[8], J. Eislöffel[6], H. Linz[16], G. Surcis[17], J. O. Chibueze[18,19], W. Baan[20] and B. Kramer[3,21]



02 Feb 2019

28 Feb 2019



Distribution translocates with 4-8% the speed of light

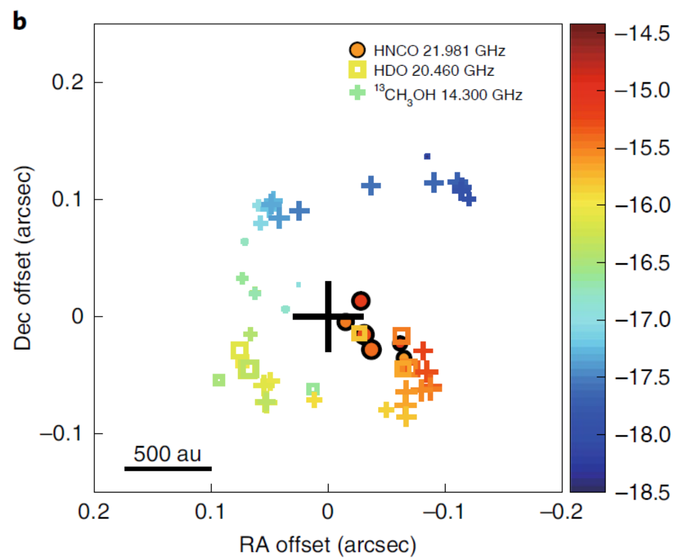
This means that excitation goes through structures with very high density material

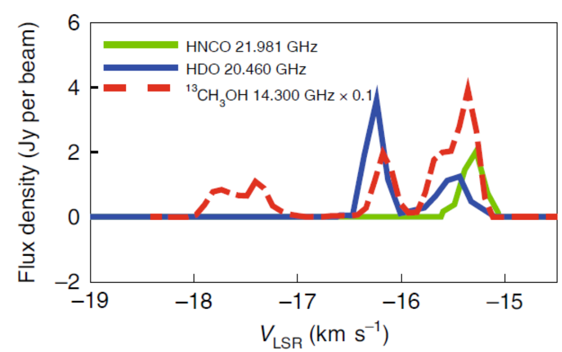
nature astronomy
LETTERS
https://doi.org/10.1038/s41550-020-1144-x

New maser species tracing spiral-arm accretion flows in a high-mass young stellar object

Xi Chen[1,2,3], Andrej M. Sobolev[4], Zhi-Yuan Ren[5], Sergey Parfenov[4], Shari L. Breen[6], Simon P. Ellingsen[7], Zhi-Qiang Shen[2,3], Bin Li[2,3], Gordon C. MacLeod[8,9], Willem Baan[10], Crystal Brogan[11], Tomoya Hirota[12,13], Todd R. Hunter[11], Hendrik Linz[14], Karl Menten[15], Koichiro Sugiyama[13,16], Bringfried Stecklum[17], Yan Gong[15] and Xingwu Zheng[18]

HNCO 21.981 GHz
HDO 20.460 GHz
$^{13}CH_3OH$ 14.300 GHz



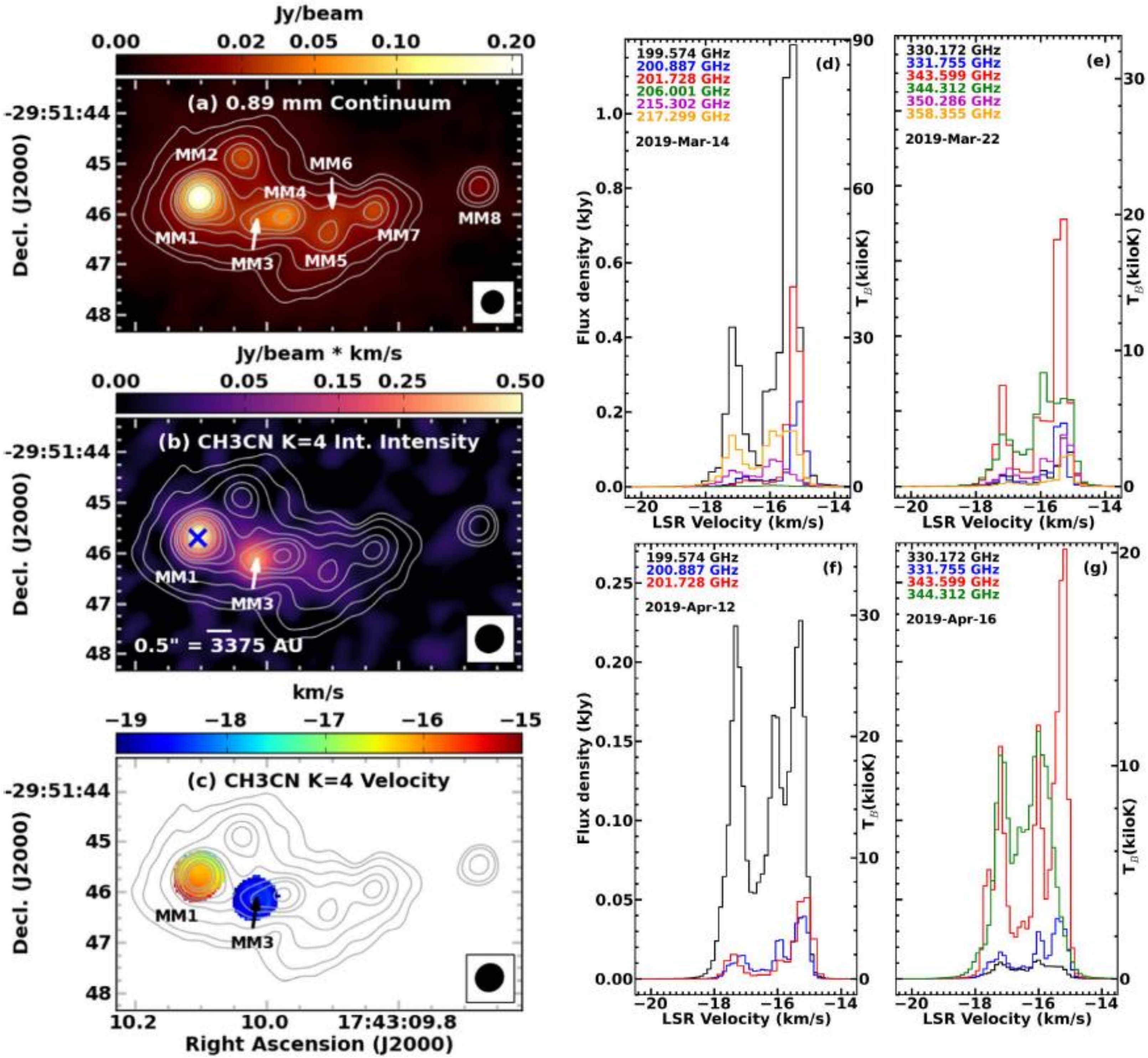


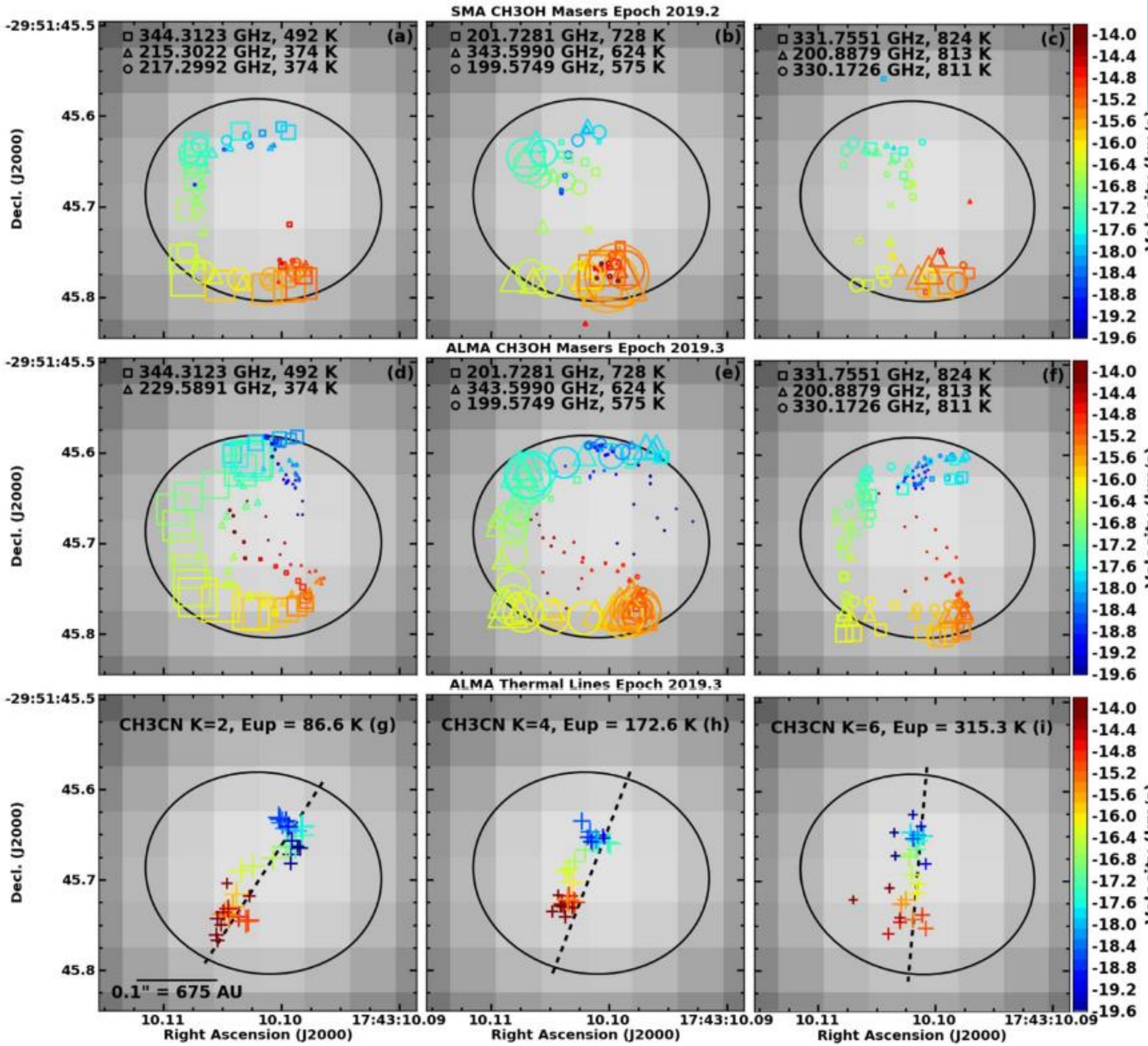
THE ASTROPHYSICAL JOURNAL LETTERS, 881:L39 (9pp), 2019

Sub-arcsecond (Sub)millimeter Imaging of the Massive Protocluster G358.93−0.03: Discovery of 14 New Methanol Maser Lines Associated with a Hot Core

C. L. Brogan[1], T. R. Hunter[1], A. P. M. Towner[1,2,27], B. A. McGuire[1,3,28], G. C. MacLeod[4,5], M. A. Gurwell[3], C. J. Cyganowski[6], J. Brand[7,8], R. A. Burns[9,10], A. Caratti o Garatti[11], X. Chen[12], J. O. Chibueze[13,14], N. Hirano[15], T. Hirota[9,16], K.-T. Kim[10], B. H. Kramer[17,18], H. Linz[19], K. M. Menten[17], A. Remijan[1], A. Sanna[17], A. M. Sobolev[20], T. K. Sridharan[3], B. Stecklum[21], K. Sugiyama[22], G. Surcis[23], J. Van der Walt[24], A. E. Volvach[25,26], and L. N. Volvach[25]

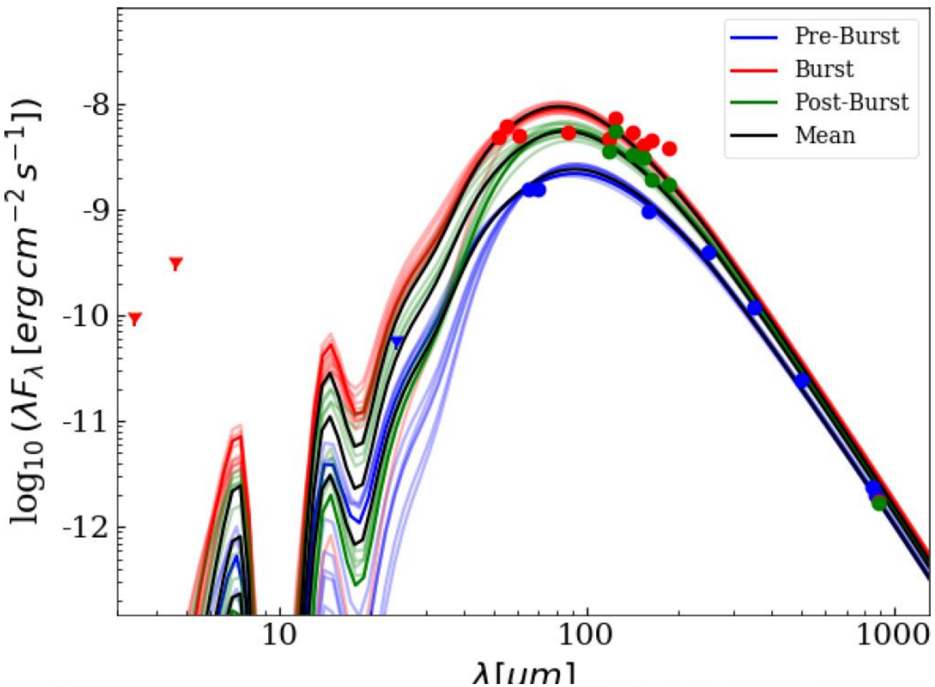
	Torsional State v_t	Transition Quantum Numbers	Rest Frequency (GHz)	SMA (2019 Mar) Integrated Flux (Jy km s^{-1})	ALMA (2019 Apr) Integrated Flux (Jy km s^{-1})	ALMA (2019 Apr) T_b[c] (K)	Integrated Flux Ratio SMA/ALMA
*	1	13_{-2}–14_{-3} $E2$	199.574851(18)	980	314.0	3.17E+6	3.12
*	1	18_{3}–19_{4} $E1$	200.887863(31)	137	40.5	1.67E+6	3.38
*	1	16_{-1}–17_{-2} $E2$	201.728147(29)	250	44.9	1.18E+6	5.56
*	0	12_{5}–13_{4} $E1$	206.001302(15)	5.0	...	...	...
*	1	6_{1}–7_{2} A^{+}	215.302206(19)	94.3	...	...	...
*	1	6_{1}–7_{2} A^{-}	217.299205(17)	246	...	...	...
*	0	15_{4}–16_{3} $E1$	229.589056(12)	...	8.6	4.82E+3	...
*	2[d]	11_{3}–12_{4} A^{-}	330.172526(22)	118	16.4	1.39E+4	7.20
*	2[d]	11_{3}–12_{4} A^{+}	330.172553(22)				
*	1	15_{-5}–16_{-6} $E2$	331.755099(32)	147	37.2	1.22E+5	3.95
*	1	13_{-1}–14_{-2} $E2$	343.599019(26)	738	204.7	1.35E+6	3.61
*	1	10_{-2}–11_{-3} $E2$	344.312267(17)	559	187.0	9.27E+4	2.99
*	1	15_{3}–16_{4} $E1$	350.286493(25)	174	...	...	...
*	1[d]	18_{4}–19_{5} A^{-}	358.354940(27)	68.0	...	...	...
*	1[d]	18_{4}–19_{5} A^{+}	358.355121(27)		...	...	...
*	1	3_{1}–4_{2} A^{-}	361.236506(17)	11.1	...	...	...


Jy/beam
0.00 0.02 0.05 0.10 0.20
(a) 0.89 mm Continuum
MM1
MM2
MM3
MM4
MM5
MM6
MM7
MM8
Decl. (J2000)
-29:51:44
45
46
47
48
Jy/beam * km/s
0.00 0.05 0.15 0.25 0.50
(b) CH3CN K=4 Int. Intensity
0.5" = 3375 AU
km/s
−19 −18 −17 −16 −15
(c) CH3CN K=4 Velocity
10.2 10.0 17:43:09.8
Right Ascension (J2000)
199.574 GHz
200.887 GHz
201.728 GHz
206.001 GHz
215.302 GHz
217.299 GHz
2019-Mar-14
(d)
330.172 GHz
331.755 GHz
343.599 GHz
344.312 GHz
350.286 GHz
358.355 GHz
2019-Mar-22
(e)
2019-Apr-12
(f)
2019-Apr-16
(g)
Flux density (kJy)
T_B(kiloK)
LSR Velocity (km/s)



Brogan C.L., Hunter T.R., Towner A.P.M. et al. 2019, ApJL, 881, L39

"Sub-arcsecond (Sub)millimeter Imaging of the Massive Protocluster G358.93-0.03: Discovery of 14 New Methanol Maser Lines Associated with a Hot Core"



Stecklum B., Wolf V., Linz H. et al.
2021, A&A, 646, 161

"Infrared observations of the flaring maser source G358.93-0.03. SOFIA confirms an accretion burst from a massive young stellar object"

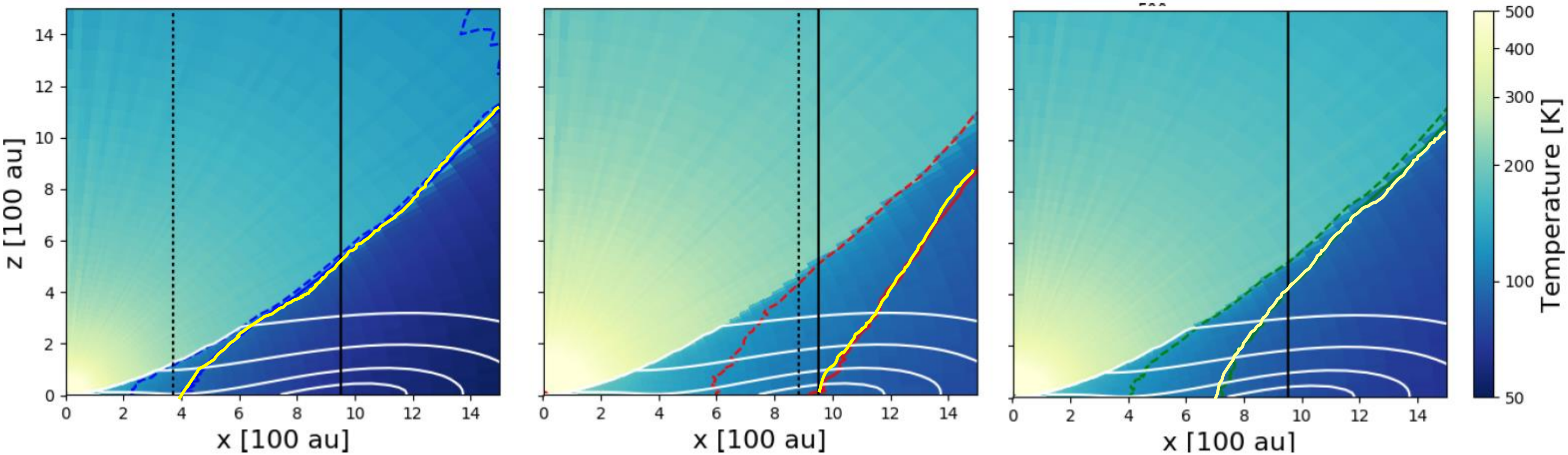


Fig. 8. Temperature distribution of the mean model in the x-z plane (innermost part of first quadrant) for the pre-burst (**left**), burst- (**center**) and post-burst epochs (**right**). The blue, red, and green lines enclose the temperature range from 94 K (solid) to 120 K (dashed) during the pre- and burst epochs, respectively. The white contours mark gas particle volume densities of $n_{\rm H} = [0.2, 0.3, 0.5, 1] \times 10^8\ {\rm cm}^{-3}$ which decrease with increasing z. The vertical solid black line indicates the outer radius of the disk. The dashed black lines mark the radius of the maser ring from the first and 4th epoch of the VLBI observations (Burns et al., in prep.; Burns et al. 2020b). The length of the black bar corresponds to 50 mas.

Accreted masses

S255IR NIRS 3 – 2 M_{Jup} (Caratti o Garatti et al., 2017)

NGC 6334 I MM1 – 0.3 M_{Jup} (Hunter et al., 2017)

G358.93-0.03 MM1 – 0.6 M_{Jup} (Stecklum et al. 2021)

These are not stellar masses!

Current models predict accretion events of the greater scale

Currently obtained results of the maser-triggered studies.

Maser studies combined with observations in the FIR and submm/mm ranges have shown high potential for the studies of the structure of the circumstellar disks of massive young stellar objects, including kinematics and magnetic fields.

Observations have shown that the structure of the circumstellar disks of massive young stellar objects is significantly inhomogeneous. They contain coherent structures up to 1000 AU in size.

Accretion of matter onto a young star can occur along some structures; these structures can be in the form of spirals.

The matter of accretion structures is inhomogeneous. Accretion of matter on the young star leads to luminosity bursts of various intensities.

A large amount of high-density matter is present in the disk structures, leading to a significant slowdown in the propagation of the energy released in the accretion burst.

After the accretion burst the physical-chemical state of the disk matter changes and does not return to its previous state.

Some future

Continue maser-monitoring-triggered research with M2O capabilities including interferometric observations with vlbi (EVN, ATCA, etc.) and mm/submm (ALMA, SMA) facilities. Relevant proposals are accepted.

Studies of chemical changes associated with the transient events using existing and newly obtained data on the line emission.

Joint efforts in monitoring with the JCMT Transient Team.

Space-borne missions in mm-submm-IR ranges can substantially increase efficiency of studies of transient events in star forming regions. This is necessary to study relatively weak events, events in the distant massive YSOs and achieve necessary statistics.

Relevant proposal is accepted for JWST.

Improve theoretical models.

Thanks for your attention!

Thanks BASIS foundation for support!