

# The accretion bursting flare in the high-mass SFR G358.93-00.03 II: VLBI monitoring

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Tomoya Hirota

KeeTae Kim

Yoshinori Yonekura

The M2O collaboration

NAOJ / KASI

NAOJ / NARIT

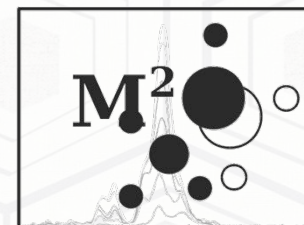
NAOJ / SOKENDAI

KASI

Ibaraki U.



East Asian Core Observatories Association



# Massive Stars ( $>8 M_{\odot}$ )



Influence Galaxies

They explode (SN)

They implode (BH)

They are mysterious

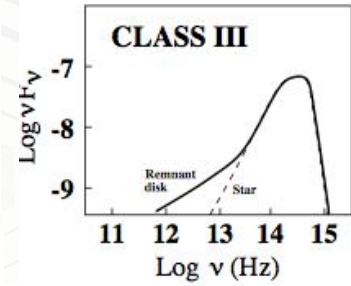
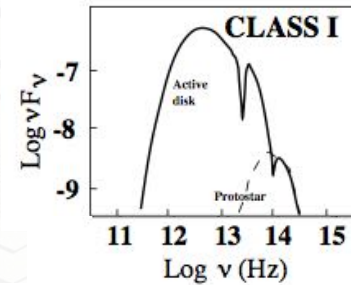
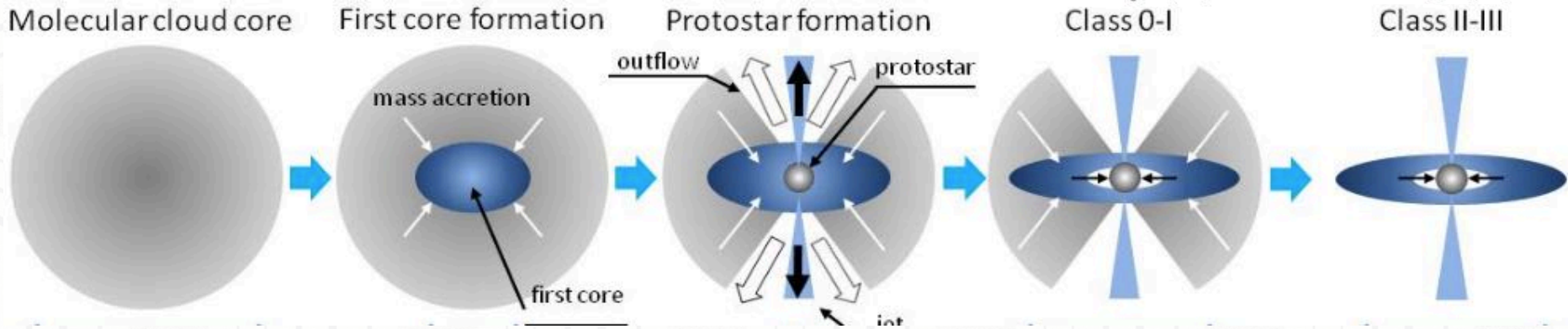
Produce  $>Fe$  elements

They are our parents

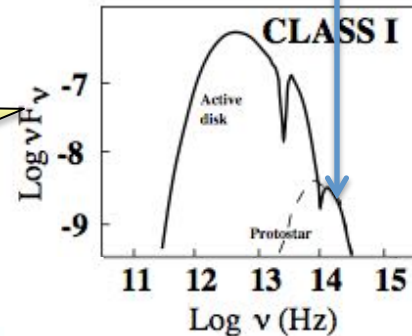
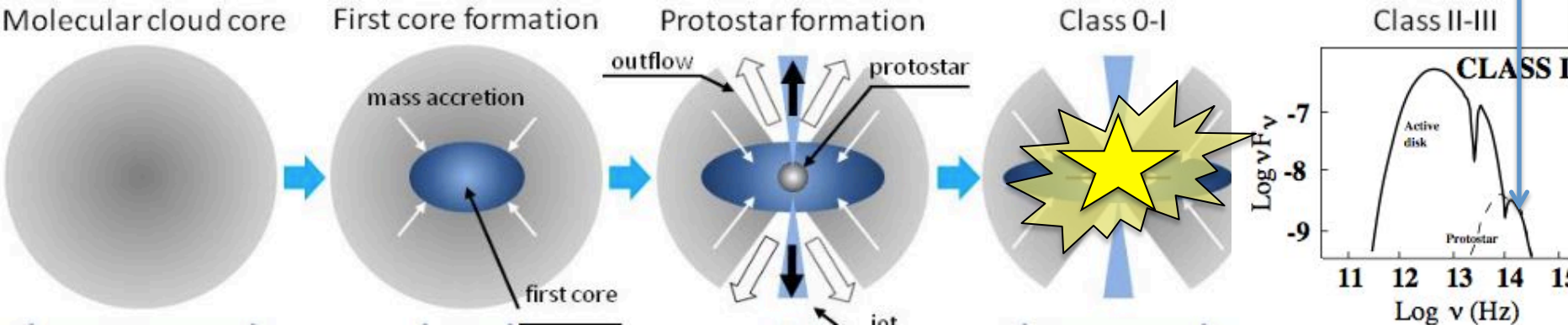
The field has become quite popular recently which helps to get jobs

# Radiation pressure

## Low mass stars:

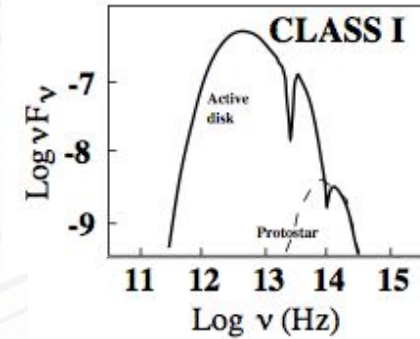
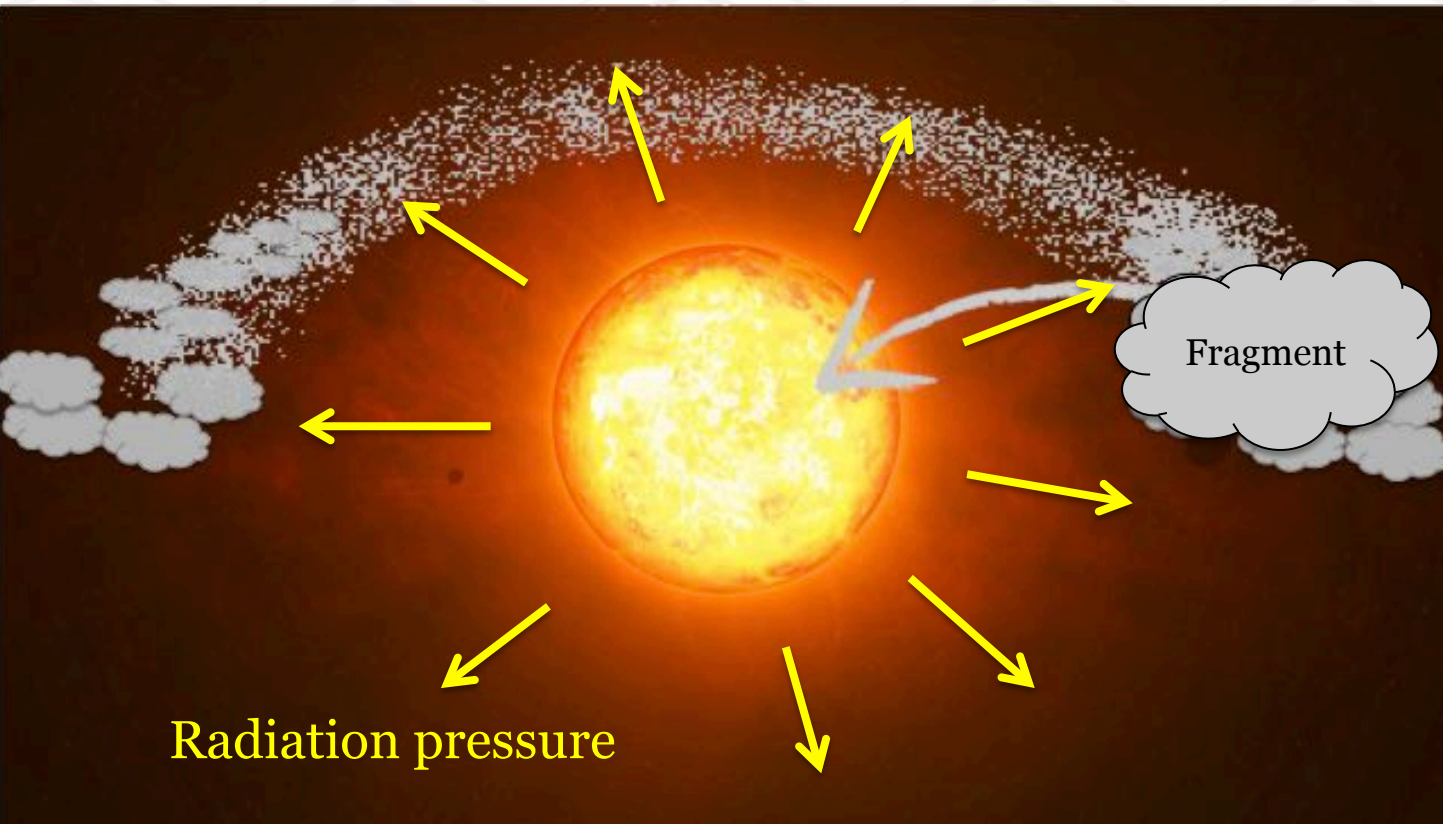


## High mass stars:



# Problem:

## Radiation pressure



Grav. contraction

$$L = 4 \pi R^2 \sigma T^4$$

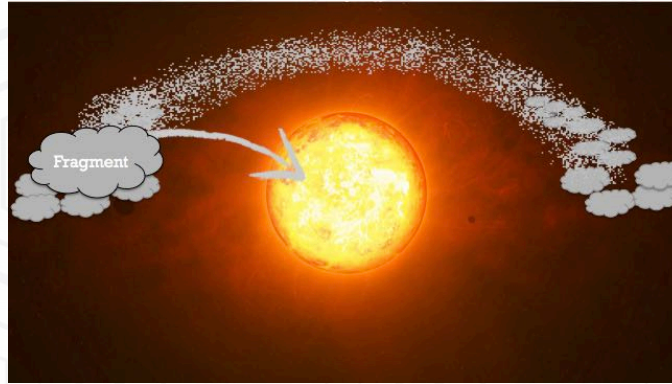
High  $T \rightarrow$  more UV

Radiation pressure (UV) increases over time until it counteracts further accretion

**This happens at  $\sim 8 M_\odot$**

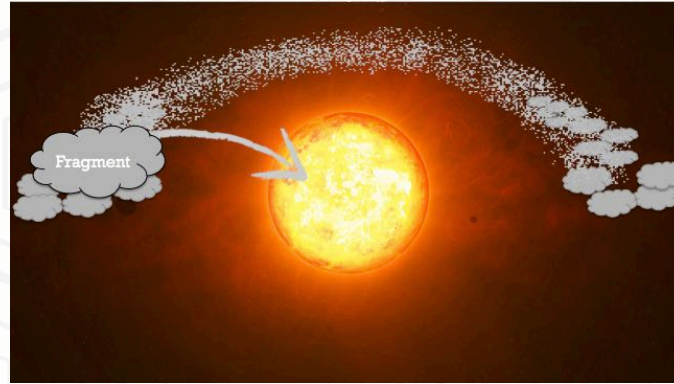
# Theoretical solution: “Episodic accretion”

Accretion from inner disk (via MRI)

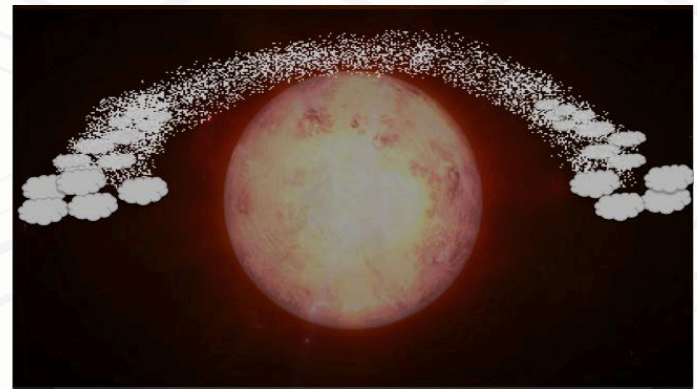


# Theoretical solution: “Episodic accretion”

Accretion from inner disk (via MRI)

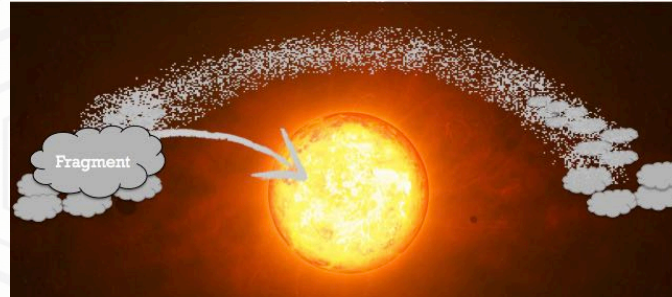


$L = 4 \pi R^2 \sigma T^4$ , star will ‘bloat’



# Theoretical solution: “Episodic accretion”

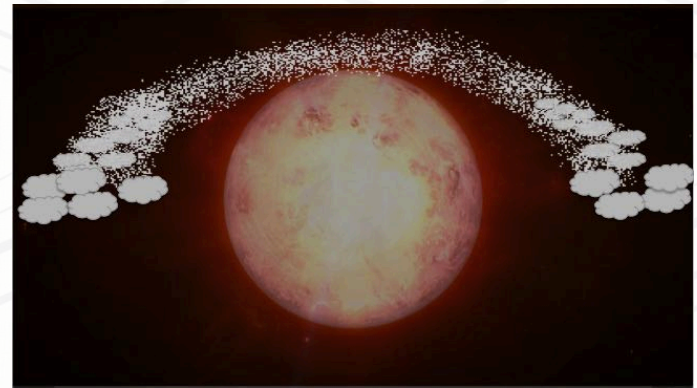
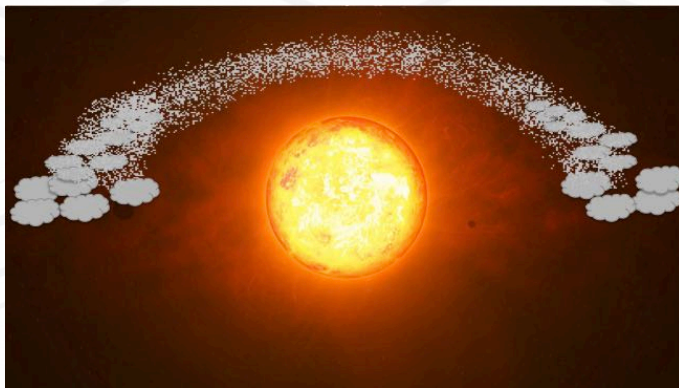
Accretion from inner disk (via MRI)



- Beat radiation pressure
- Build very massive stars

Gravitational contraction

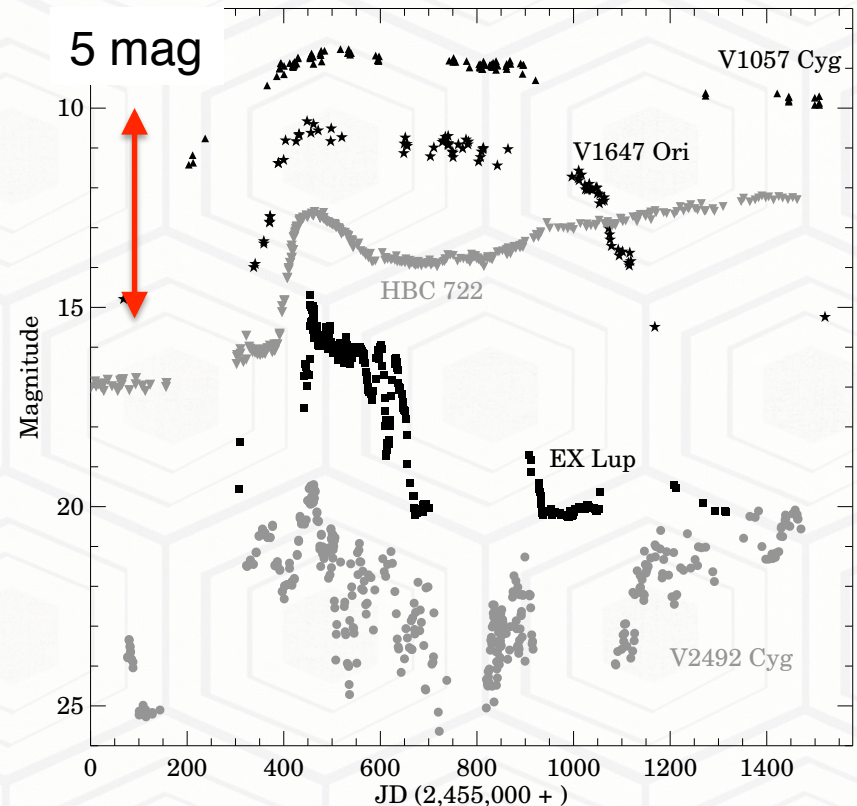
$L = 4 \pi R^2 \sigma T^4$ , star will ‘bloat’



Reference: Hosokawa et al., 2016, ApJ, 824, 119

# Episodic accretion: in low mass star formation

- Discovered in low-mass star-forming regions (e.g., Herbig 66,77)
- Luminosity/Accretion rate increase 1-3 order of mag.!
- Classified into 3 types (see Audard 14; Contreras Pena+ 16)
  - FUors: High amp & Longer > 10 yr
  - EXors: Moderate & Shorter < 1.5 yr
  - MNors: 1.5 yr < & < 10 yr
- Resolve *luminosity problem*



Light curve at Optical-bands  
(Kospal+ 2011; Audart+ 2014)



# Episodic accretion: Known accretion bursts

**S255NIRS3**

**NGC6334I**

LETTERS

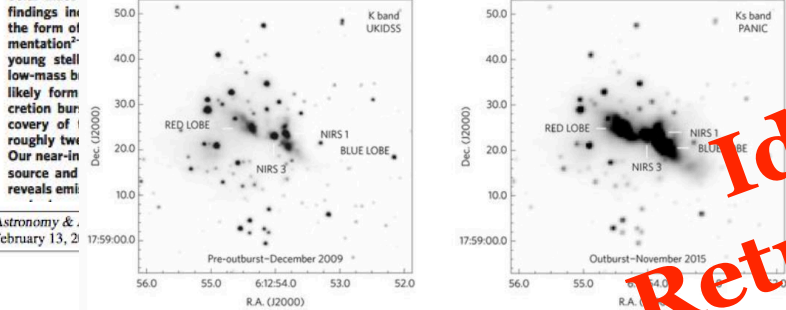
PUBLISHED ONLINE 14 NOVEMBER 2016 | DOI: 10.1038/NPHYS3942

nature  
physics

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

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

Solar-mass stars form via disk-mediated accretion. Recent archival images taken with the UKIRT Infrared Deep Sky Survey



Astronomy & Astrophysics, February 13, 2017

## Radio outburst from a massive (proto)star \*

When accretion turns into ejection

R. Cesaroni<sup>1</sup>, L. Moscadedelli<sup>1</sup>, R. Neri<sup>2</sup>, A. Sanna<sup>3</sup>, A. Caratti o Garatti<sup>4</sup>, J. Eislöffel<sup>5</sup>, C. M. Walmsley\*\*

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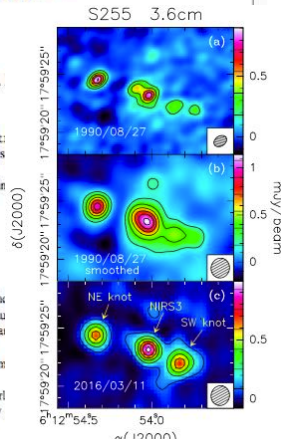
Received date; accepted date

ABSTRACT

Context. Recent observations of the massive young stellar object S255 NIRS 3 have revealed a large in density and IR emission, which have been interpreted as the result of an accretion outburst, possibly due to disk. This indicates that this type of accretion event could be common in young/forming early-type stars as supports the idea that accretion onto the star may occur in a non-continuous way.

Aims. As accretion and ejection are believed to be tightly associated phenomena, we wanted to confirm outburst in S255 NIRS 3 by detecting the corresponding burst of the associated thermal jet.

Methods. We monitored the radio continuum emission from S255 NIRS 3 at four bands using the Karl millimetre continuum emission was also observed with both the Northern Extended Millimeter Array Millimetre/submillimetre Array.



Identified Retrospectively

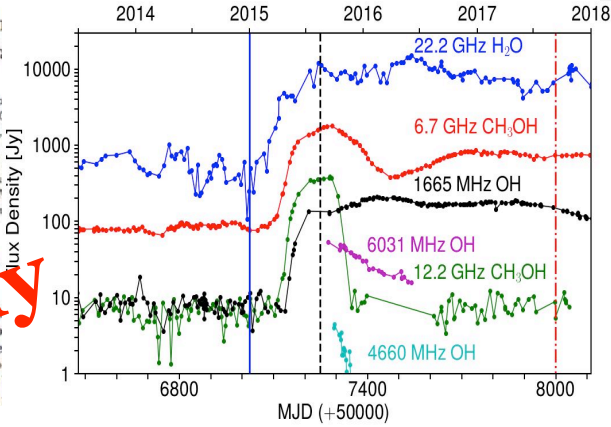
MNRAS 000, 1–17 (2018)

Preprint 17 April 2018

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

G. C. MacLeod<sup>1\*</sup>, D. P. S. J. O. Chibueze<sup>3,5,6</sup>, S. P. v. J. D. Paulsen<sup>8</sup>

<sup>1</sup>Hartebeesthoek Radio Astronomy Observatory, Dept of Mathematical Sciences, UNISA, Pietermaritzburg, South Africa, <sup>2</sup>SKA SA, The Park, Park Road, Pinelands, <sup>3</sup>NRAO, 520 Edgemont Rd, Charlottesville, <sup>4</sup>Space Research Unit, Physics Department, <sup>5</sup>Department of Physics and Astronomy, <sup>6</sup>School of Physical Sciences, University of the Free State, <sup>7</sup>Trinity House High School, Little Falls, South Africa



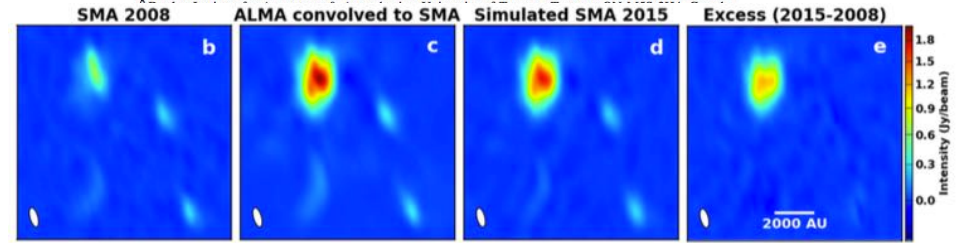
THE ASTROPHYSICAL JOURNAL LETTERS, 837:L29 (6pp), 2017 March 10

<https://doi.org/10.3847/2041-8213/aa5d0e>

## An Extraordinary Outburst in the Massive Protostellar System NGC 6334I-MM1: Quadrupling of the Millimeter Continuum

T. R. Hunter<sup>1</sup>, C. L. Brogan<sup>1</sup>, G. MacLeod<sup>2</sup>, C. J. Cyganowski<sup>3</sup>, C. J. Chandler<sup>4</sup>, J. O. Chibueze<sup>5,6,7</sup>, R. Friesen<sup>8</sup>, R. Indebetouw<sup>1,9</sup>, C. Thesner<sup>7</sup>, and K. H. Young<sup>10</sup>

<sup>1</sup>NRAO, 520 Edgemont Road, Charlottesville, VA 22903, USA; [thunter@nrao.edu](mailto:thunter@nrao.edu) <sup>2</sup>Hartebeesthoek Radio Astronomy Observatory, P.O. Box 443, Krugersdorp 1740, South Africa <sup>3</sup>SUPA, School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, UK <sup>4</sup>NRAO, P.O. Box O, Socorro, NM 87801, USA <sup>5</sup>Department of Physics and Astronomy, Faculty of Physical Sciences, University of Nigeria, Carver Building, 1 University Road, Nsukka, Nigeria <sup>6</sup>SKA Africa, 3rd Floor, The Park, Park Road, Pinelands, Cape Town 7405, South Africa <sup>7</sup>Centre for Space Research, Physics Department, North-West University, Potchefstroom 2520, South Africa <sup>8</sup>Trinity House High School, Little Falls, South Africa <sup>9</sup>Trinity House High School, Little Falls, South Africa <sup>10</sup>Trinity House High School, Little Falls, South Africa

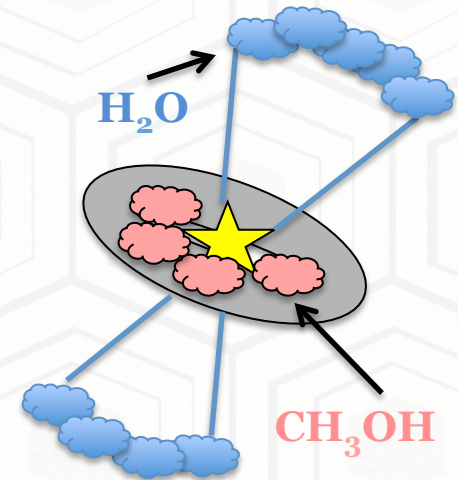


[astro-ph.SR] 12 Feb 2018

# Episodic accretion in high-mass stars

Open questions in **episodic** high-mass SF:

- Significant mass accretion?
- Mechanism?
- Timescales?
- Variety? (Exor / MNor / FUor)



**6.7 GHz Methanol masers: observational tool**

# [M2O] Maser Monitoring Organization

(Led by G. MacLeod & S. Goedhart in South Africa)

**Launch:** 2017/09/07 @IAU Symp. 336

**Aim:** Unique flux monitor & Follow-up at Radio/NIR

**Participants:** Australia, Canada, China, France, Italy, Japan, Korea, Latvia, Poland, Russia, South Africa, Thailand, Ukraine, USA



© Dr. G. MacLeod

# Observations

**【Telescope】** Hitachi 32-m (Yonekura+ 16)

**【Frequency】** 6.664-6.672 GHz

**【High-cadence monitor】** On-going from Dec 30, 2019

**【Detection mode of drastic rising-up】** Operators (mainly undergraduate/graduated students) make data reduction via script and check/report to ML in Ibaraki Univ. lab

**【G 358.93-00.03: Interval of monitor obs】**

- ~ 2019/01/14: once / 45-50 d
- 2019/01/16 ~: 毎日

**【G 358.93-00.03】**

- Distance: 6.5/10 kpc (kinetic)
- MM1/MM3: Line-rich, Hot core
  - MM1: Possible accretion disk

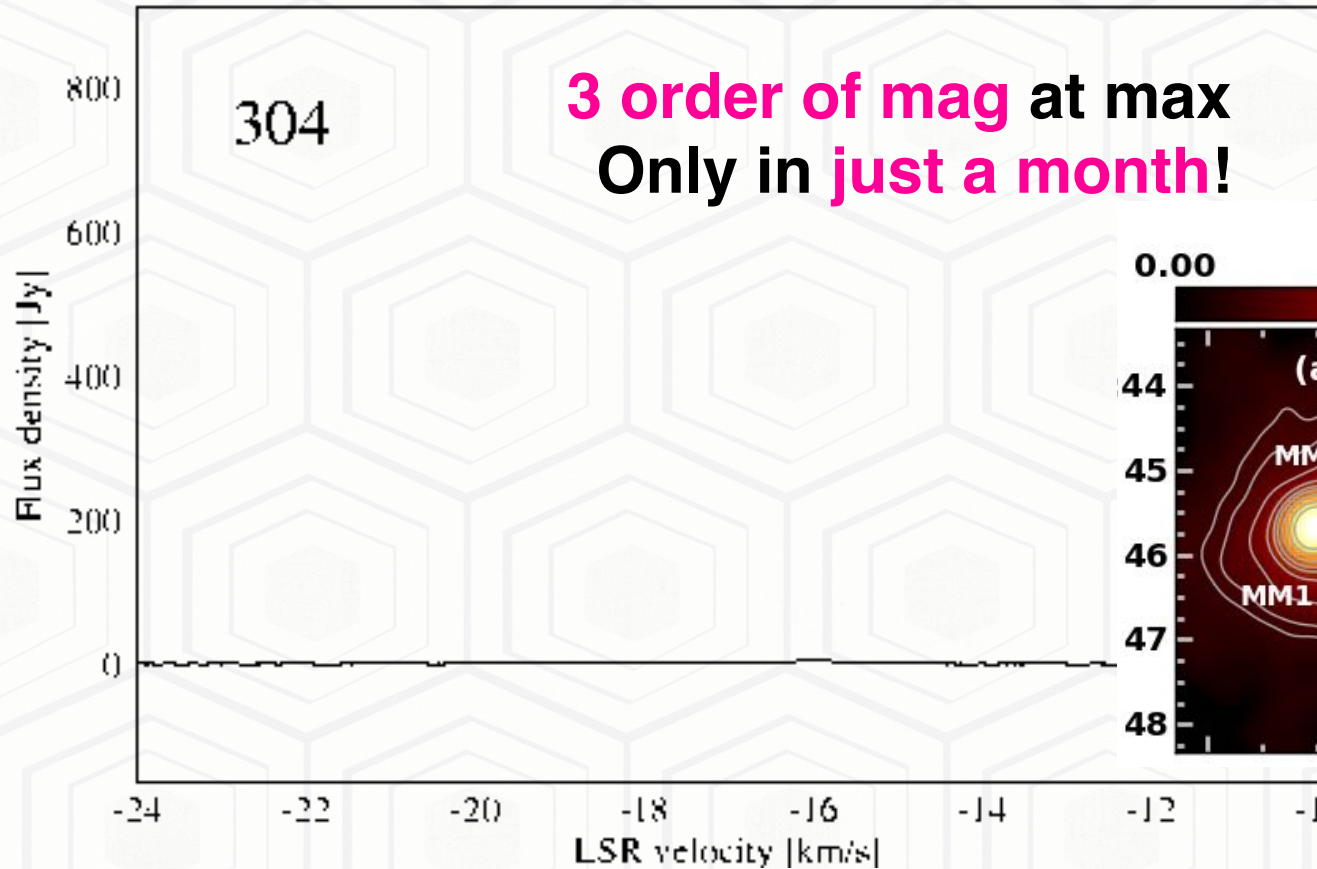


Hitachi 32-m radio telescope  
(Credit: NAOJ)

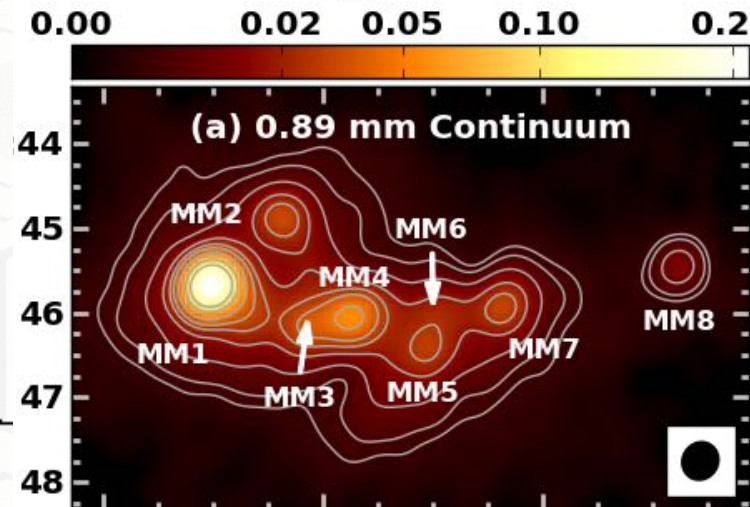
See poster by K.  
Sugiyama (P21)

# High-mass YSO: G358.93-0.03

18304060900



Brogan, Hunter+ (19)



# VLBI follow-up: Long Baseline Array (LBA)

Hartebeesthoek

ASKAP  
Yarragadee

Ceduna

ATCA  
Parkes  
Tidbinbilla

Mopra

Hobart

Warkworth

## 【Telescopes】

ATCA, Ceduna, Hobart, Mopra, Warkworth, Hartebeesthoek

ATCA, Ceduna, Hobart, Mopra, Warkworth, Parkes

## 【Obs】

2<sup>nd</sup> Feb 2019 (half month after burst)

28<sup>th</sup> Feb 2019

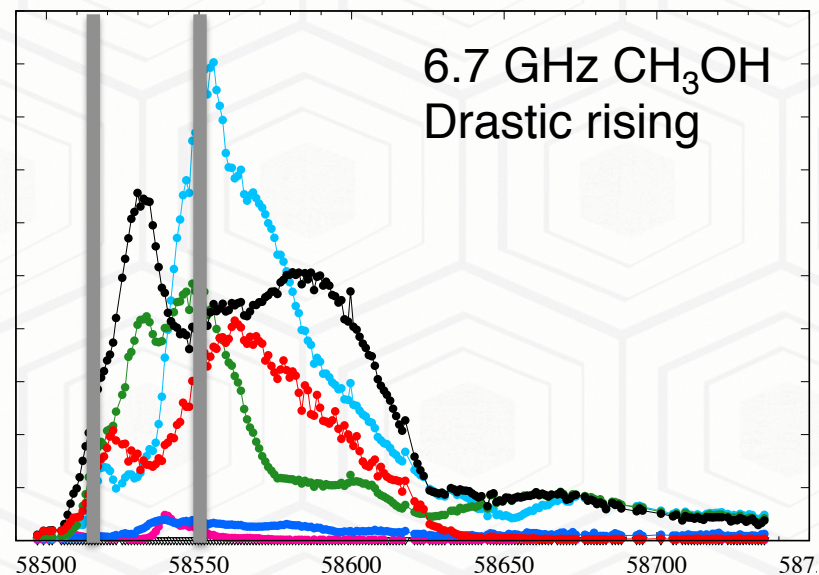
## 【Freq.】

6.668 GHz

## 【Vel. spacing】

0.045 km/s

## 【Note】 Phase referencing

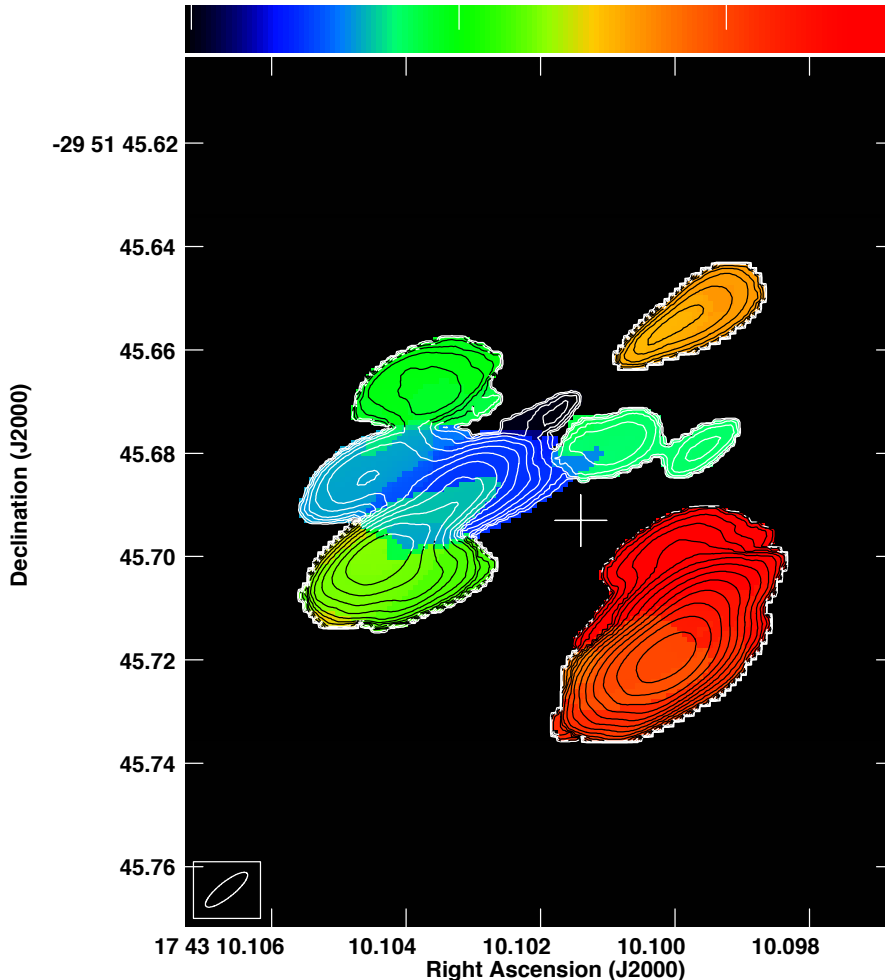


# VLBI follow-up:

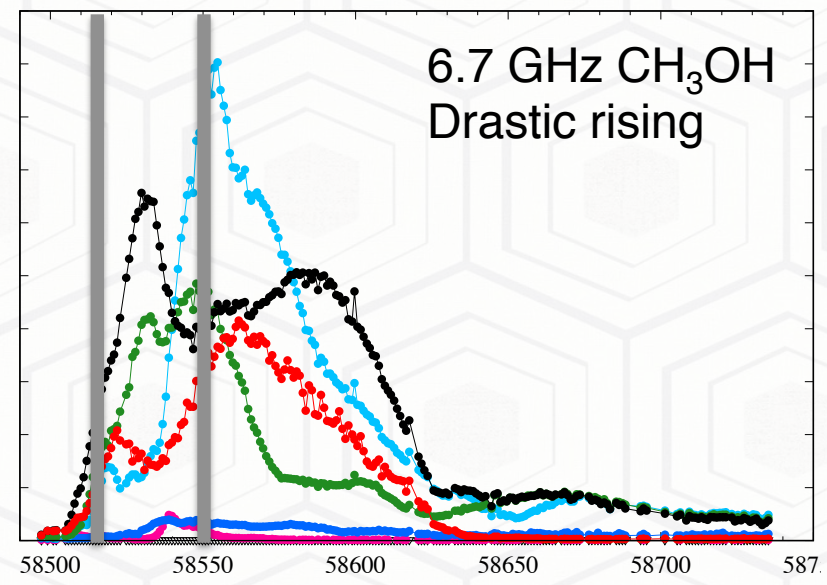
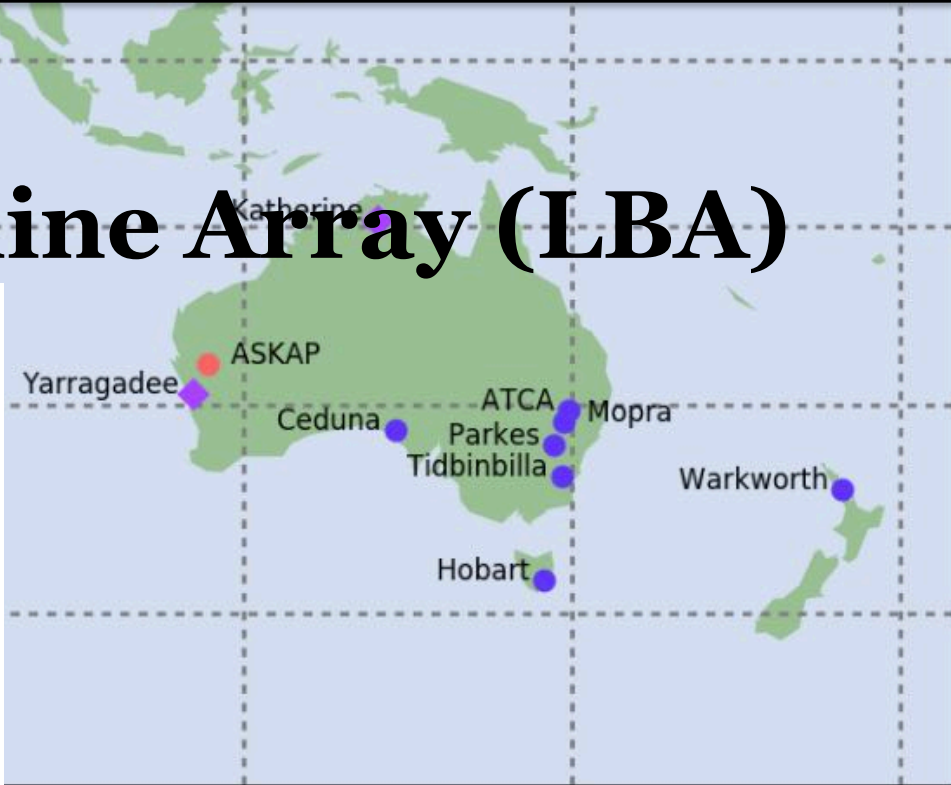
# Long Baseline Array (LBA)

GREY: G358 IPOL absCUBE.MEAN.13  
CONT: G358 IPOL absCUBE.SUMM.13

-20 -18 -16

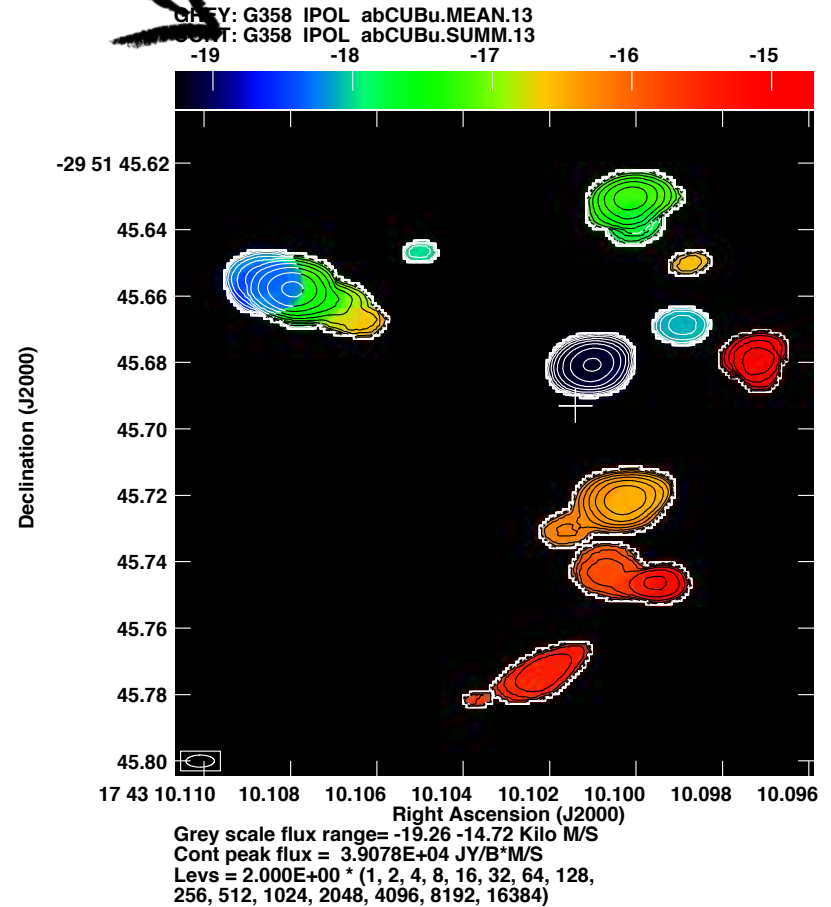
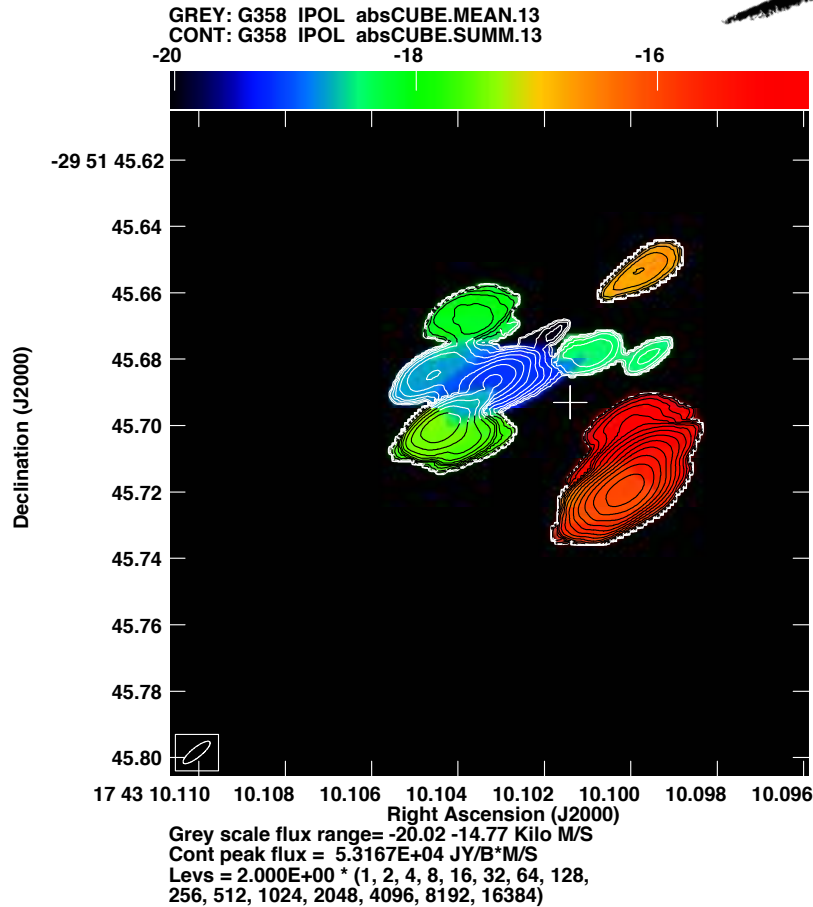


Grey scale flux range = -20.02 -14.77 Kilo M/S  
Cont peak flux =  $5.3167 \times 10^4$  JY/B\*M/S  
Levs =  $2.000 \times 10^0 * (1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384)$



# Results

26 days

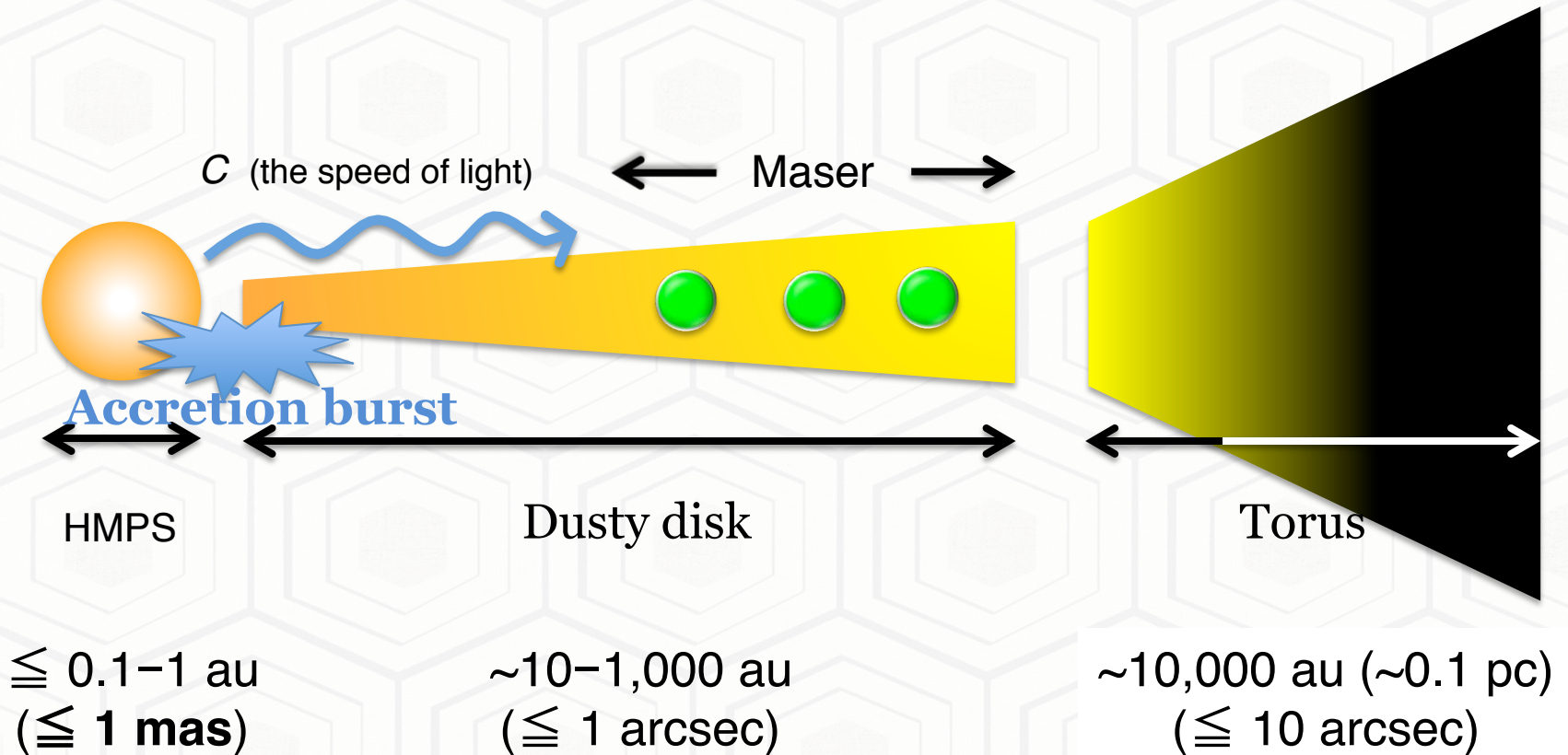


Implies a translocation of **1-2 mas/day**, which is **11,700 to 23,400 km/s** at the source's kinematic distance of 6.75 kpc (equivalent to **0.04 to 0.08c**).

**Methanol masers die at  $v > 10$  km/s i.e. Too fast to be proper motion**



# Mechanism

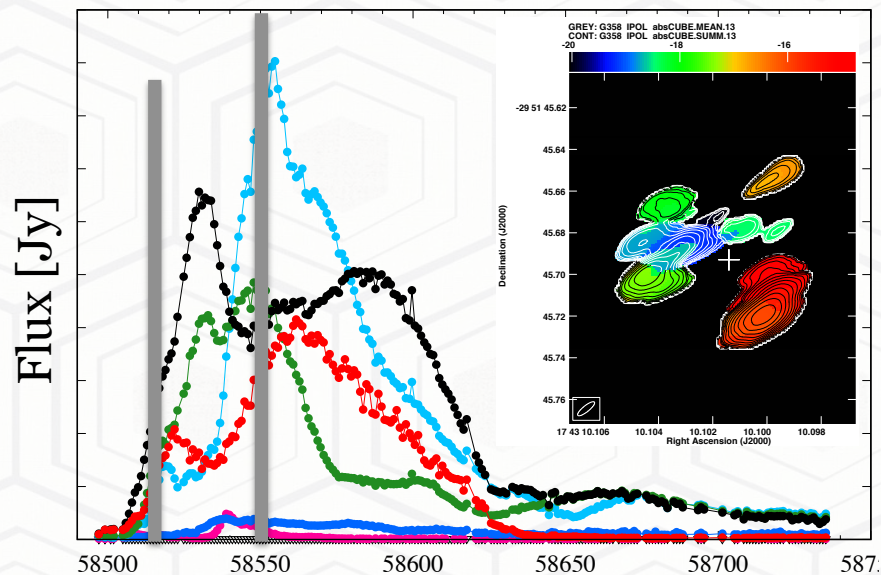


- **Thermal energy from the accretion event propagates outward**
- **Masers are created / destroyed at ever-increasing radii**
- **Strong support for an accretion event**

# Concluding viewpoints:

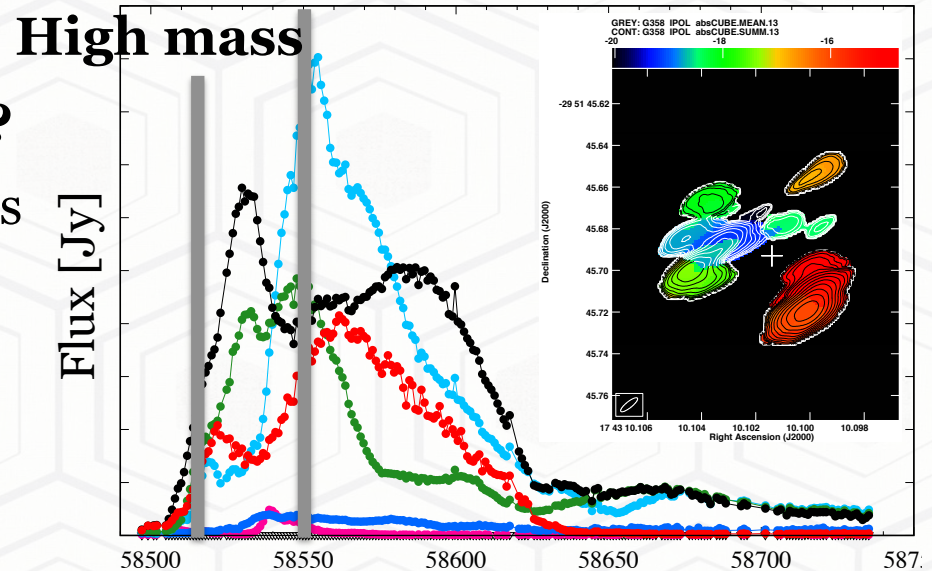
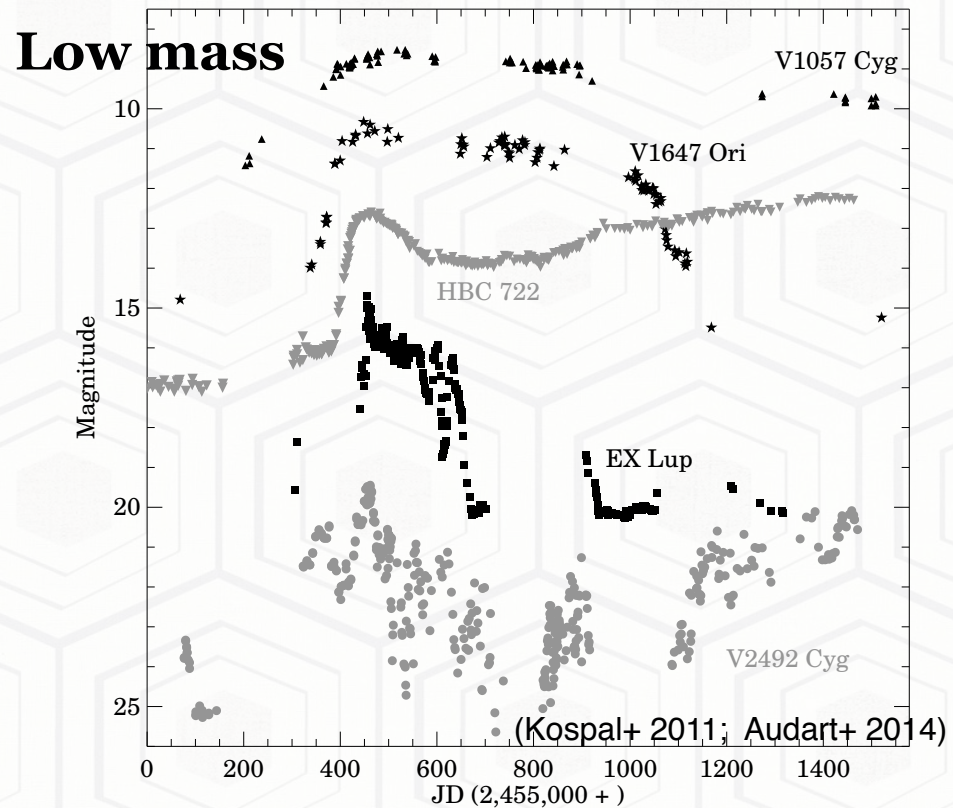
- The M2O: effective communication and follow-up
- Observed a “heat-wave” from the G358 accretion burst
- Extreme maser evolution
- Fast VLBI responses critical
- Dissimilar to S255 / NGC6334

G358 6.7 GHz



# Future work: Questions:

- **Massive EX/MN/FU-Ors?**  
a possible 'zoo' of HM bursts?
- **How much mass accreted?**  
how to determine this?
- **What initiates accretion bursts?**  
deeper understanding of mechanisms
- **What else can be learned?**  
refine the investigative process

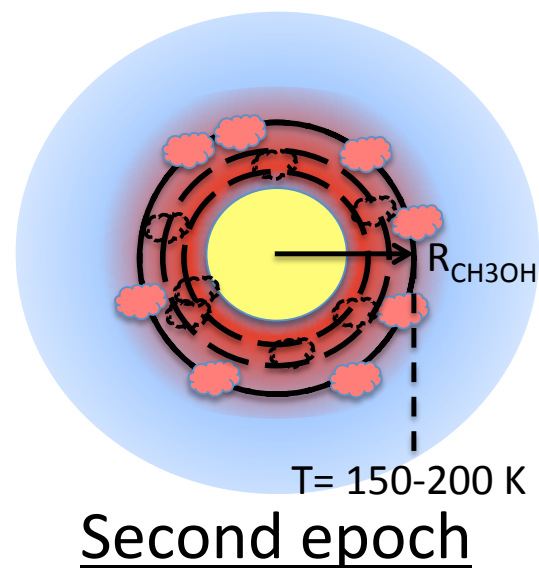
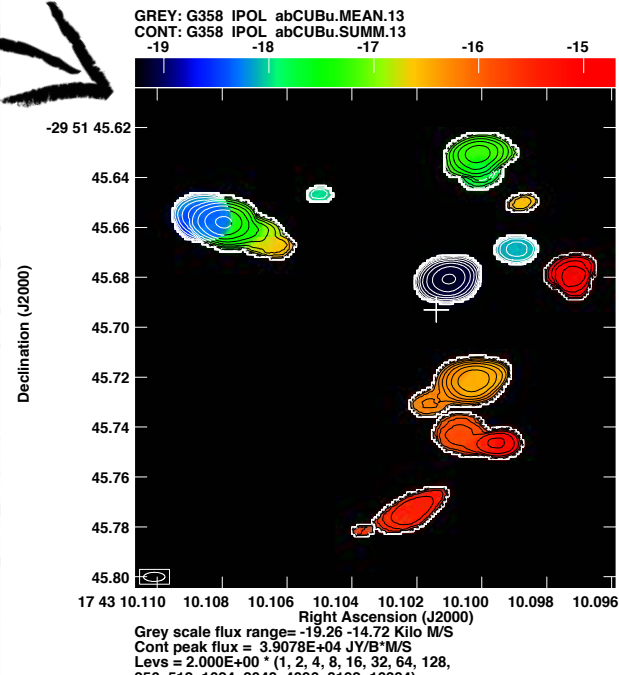
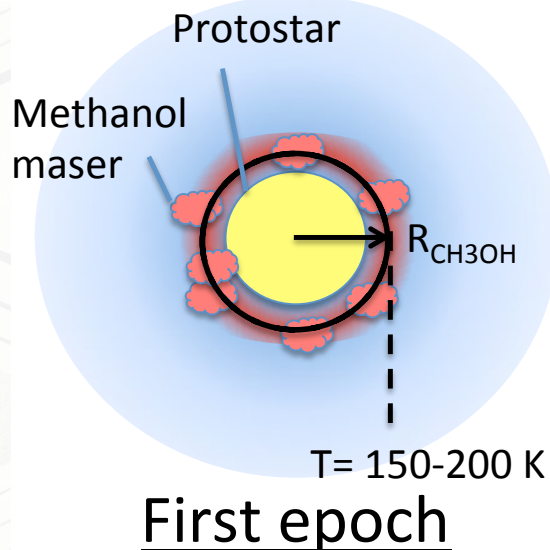
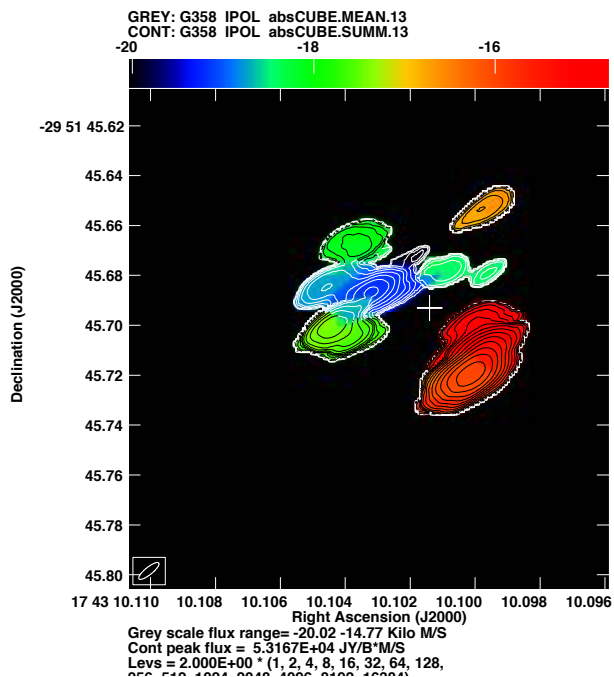




**Thank you**

# Results

26 days



# Mechanism

