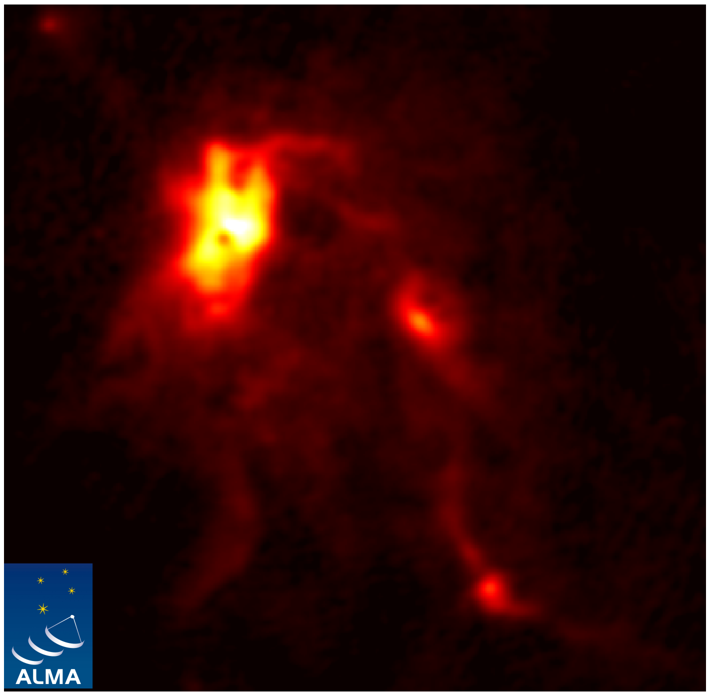
# Dramatic changes in the massive protostellar system NGC6334I-MM1 from an ongoing accretion outburst




1 mm image of NGC6334I - 200 AU resolution

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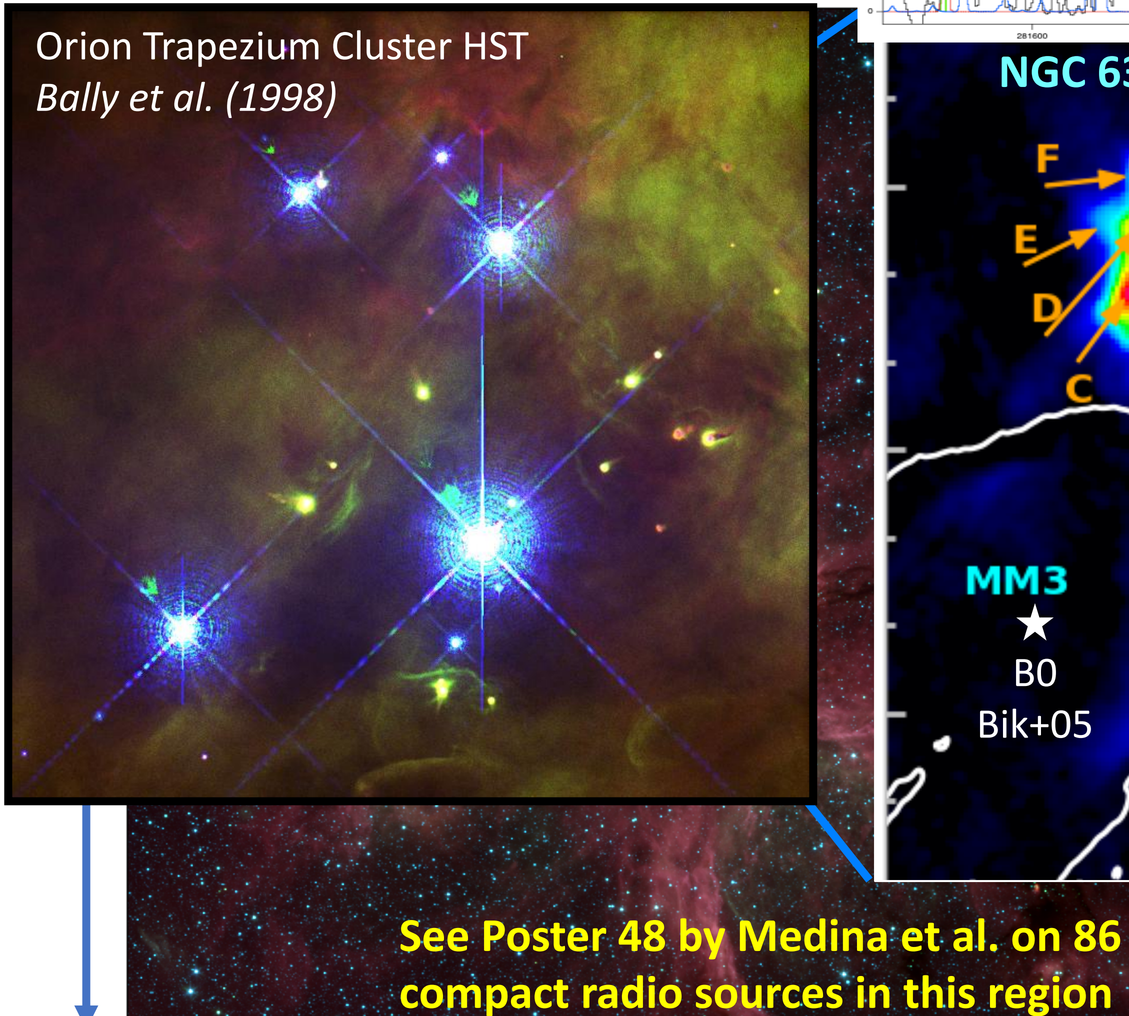
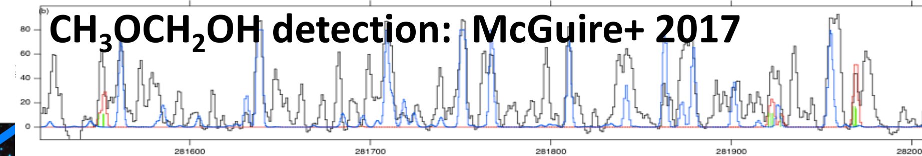
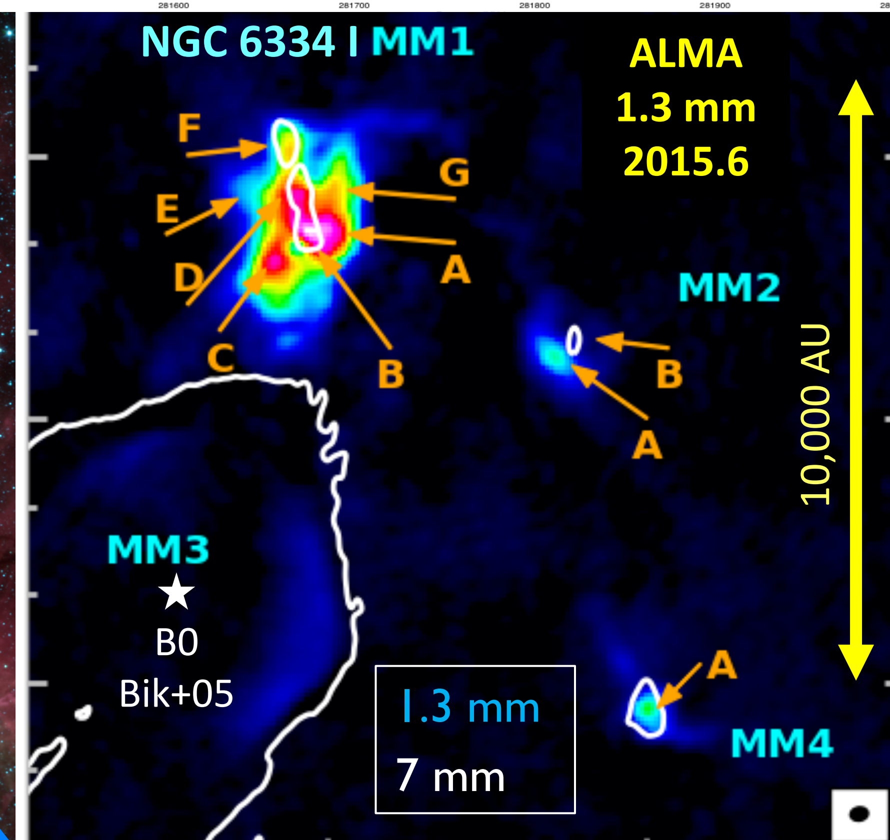
Olympian Symposium 2018: Gas and stars from milli- to mega- parsecs;
Paralia Katerini, Mount Olympus, Greece. 28 May - 1 June 2018

# NGC 6334 ``Mini-starburst''




**See Poster 48 by Medina et al. on 86 compact radio sources in this region**

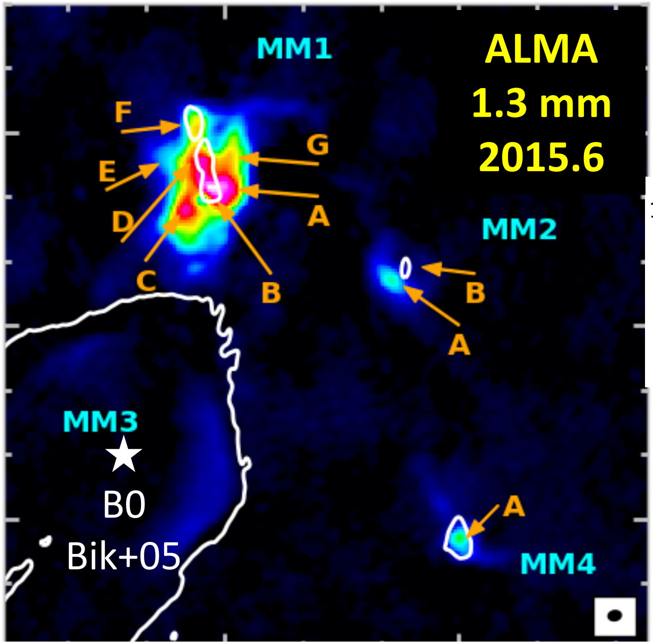
**First ALMA Image: Cycle 2, 1.3 mm**

**Resolution: 0."17 (220 au)**

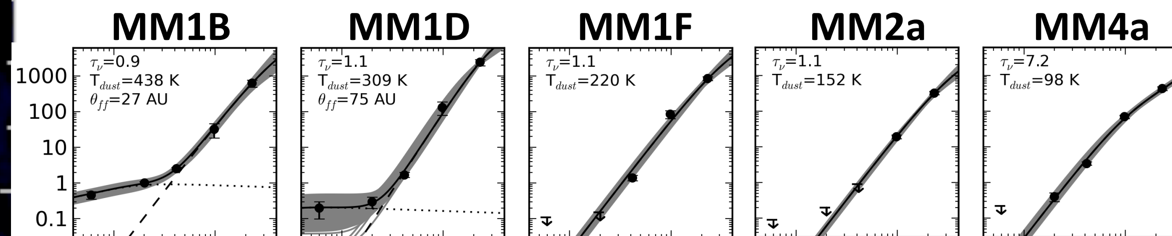
**Heavily-obscured:** only MM3 seen at 18μm (DeBuizer+2002)

# NGC 6334 I: A Diverse Protocluster

**Brogan, Hunter+ 2016, ApJ**




**SED models:** other than MM1B+D and the UCHII region MM3, most MM sources can be fit by dust emission alone



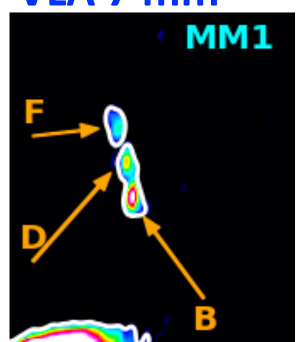

However, some MM1 components should have shown <u>much</u> brighter 7mm dust emission than observed in 2011.3. Mystery!

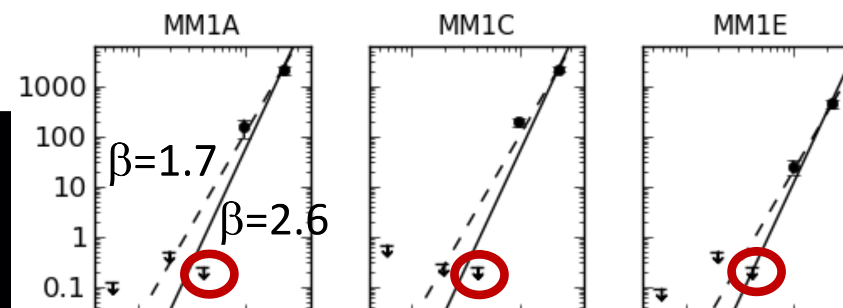
Dust sources MM1B and D also show free-free emission (VLA):

**B: Hypercompact (HC) HII region**
($n_e$=3x10$^6$ cm$^{-3}$, hot dust 440 K)

**D:** Jet+250K dust ($n_e$=3x10$^5$ cm$^{-3}$)

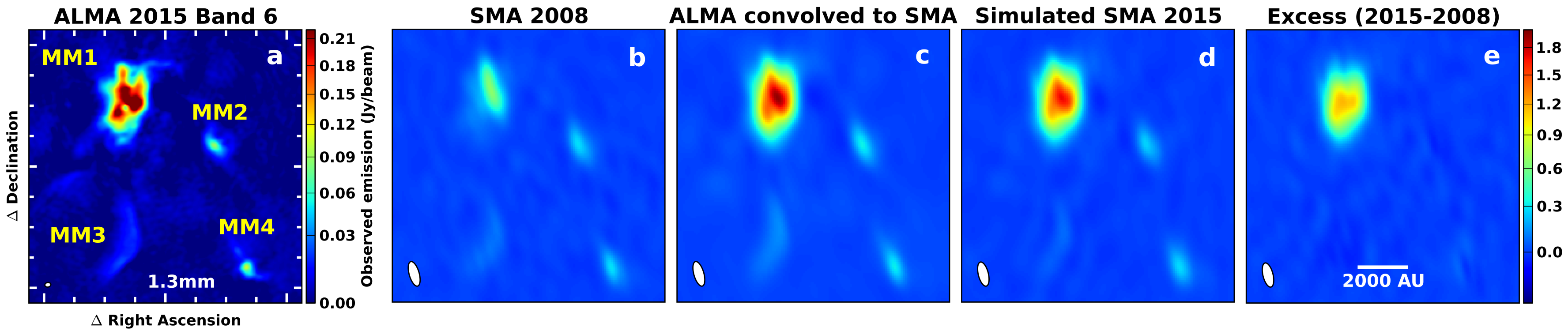
**Epoch 2011.3**
**VLA 7 mm**




Fit would require non-physical β values. Suggests they are **time-variable!**

# Extraordinary submillimeter brightening (between 2008-2015)

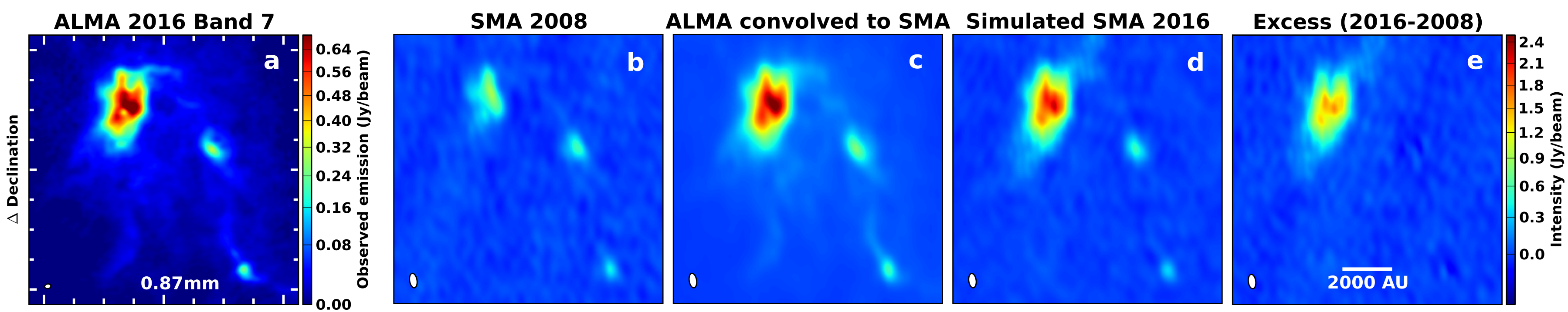



**MM1 Band 6 flux density:** 2008.6 SMA: 2.34 Jy vs. 10.8 Jy in 2015.6 ALMA

- CASA Simulation: SMA could have recovered: 9.4 Jy

*Hunter, Brogan+ 2017*

- Increase = factor of 3.9! No change in other 3 sources. **Excess centered on MM1B HCHII**



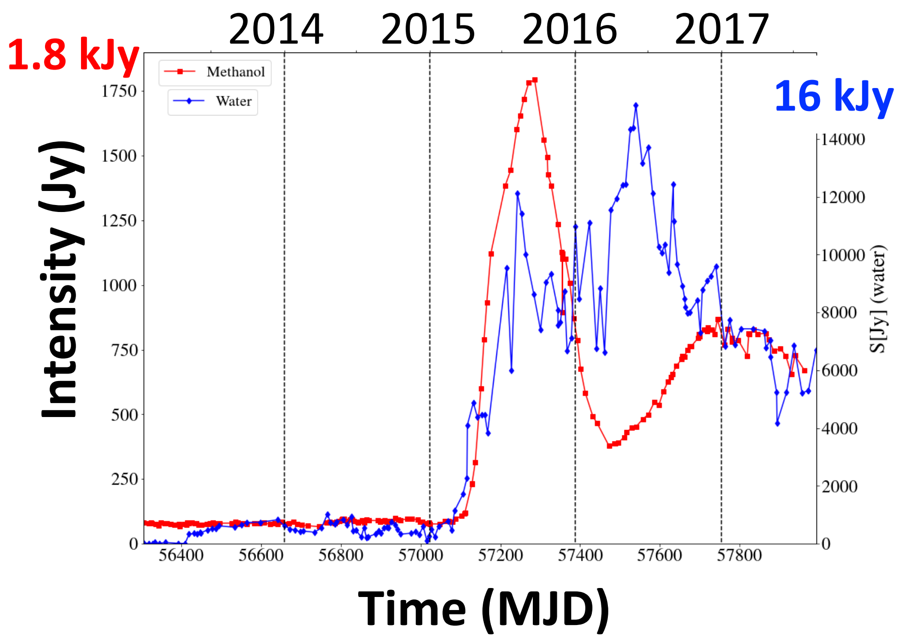

**MM1 Band 7 flux density:** Consistent increase = 21 Jy = factor of 4.2

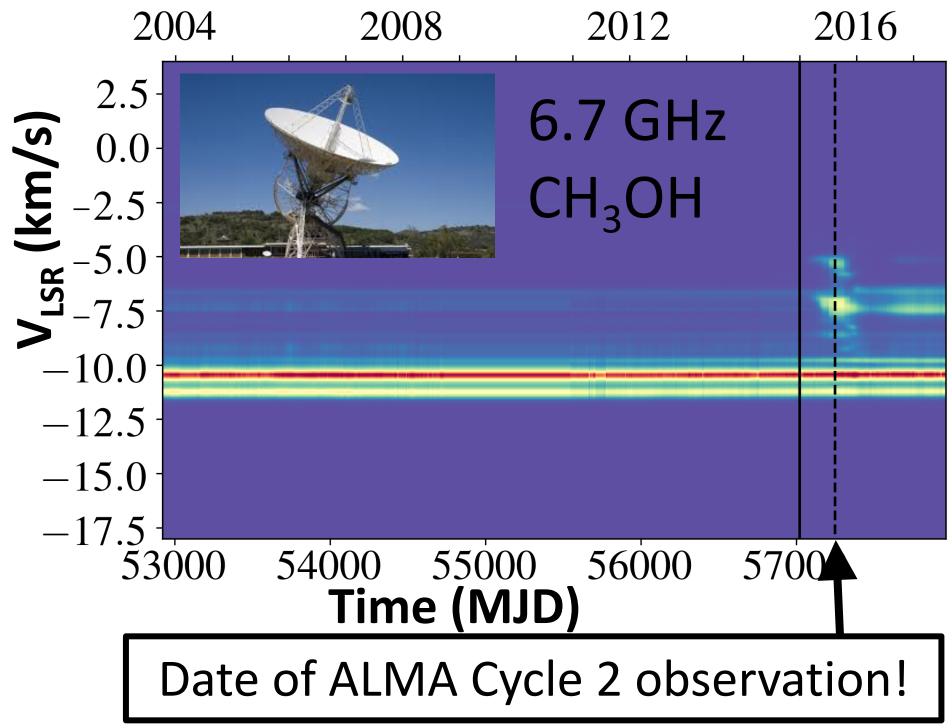
Spectral index of excess: 2.6 (dust); Planck $T_B$ up by x 2.9 → **Luminosity up factor of 70±20**

# Unprecedented maser outburst: single dish monitoring

- HartRAO 26m dish South Africa: 2 decades monitoring $H_2O$, OH, $CH_3OH$ (Goedhart+2004)
- Starting in Jan. 2015: 10 maser lines flared; 30x increase in 22 GHz $H_2O$ and 6.7 GHz $CH_3OH$

**-7.2 km/s Methanol & Water over time**

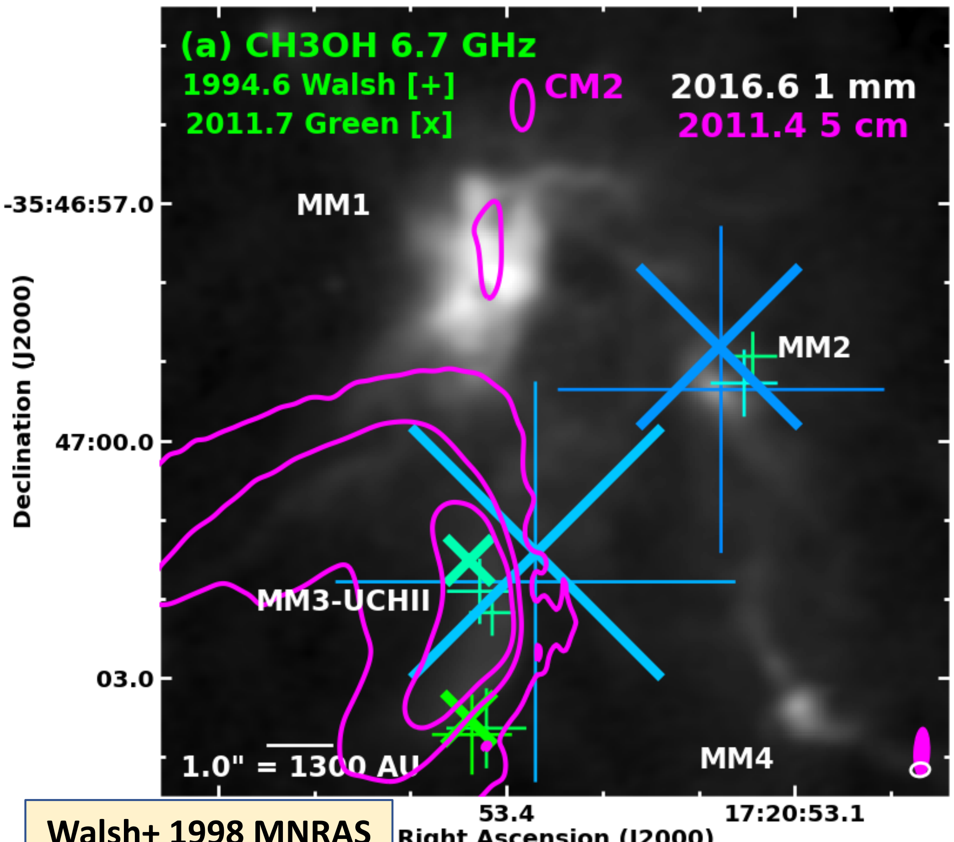



*G. MacLeod+ 2018 MNRAS, in press*

# Location of $CH_3OH$ masers in older observations

**ATCA 1994 & 2011** Spot size $\propto \sqrt{\text{flux}}$




Walsh+ 1998 MNRAS

**Important fact:**

Class II $CH_3OH$ masers are pumped by mid-IR (20-30 μm) photons (Sobolev+ 1997), in gas $n_H = 10^{4\text{-}8}$ cm$^{-3}$

Will respond to a luminosity outburst if the optical depth between masing gas and the protostar is not too high.

# VLA-A follow-up: First detection of $CH_3OH$ masers toward MM1!

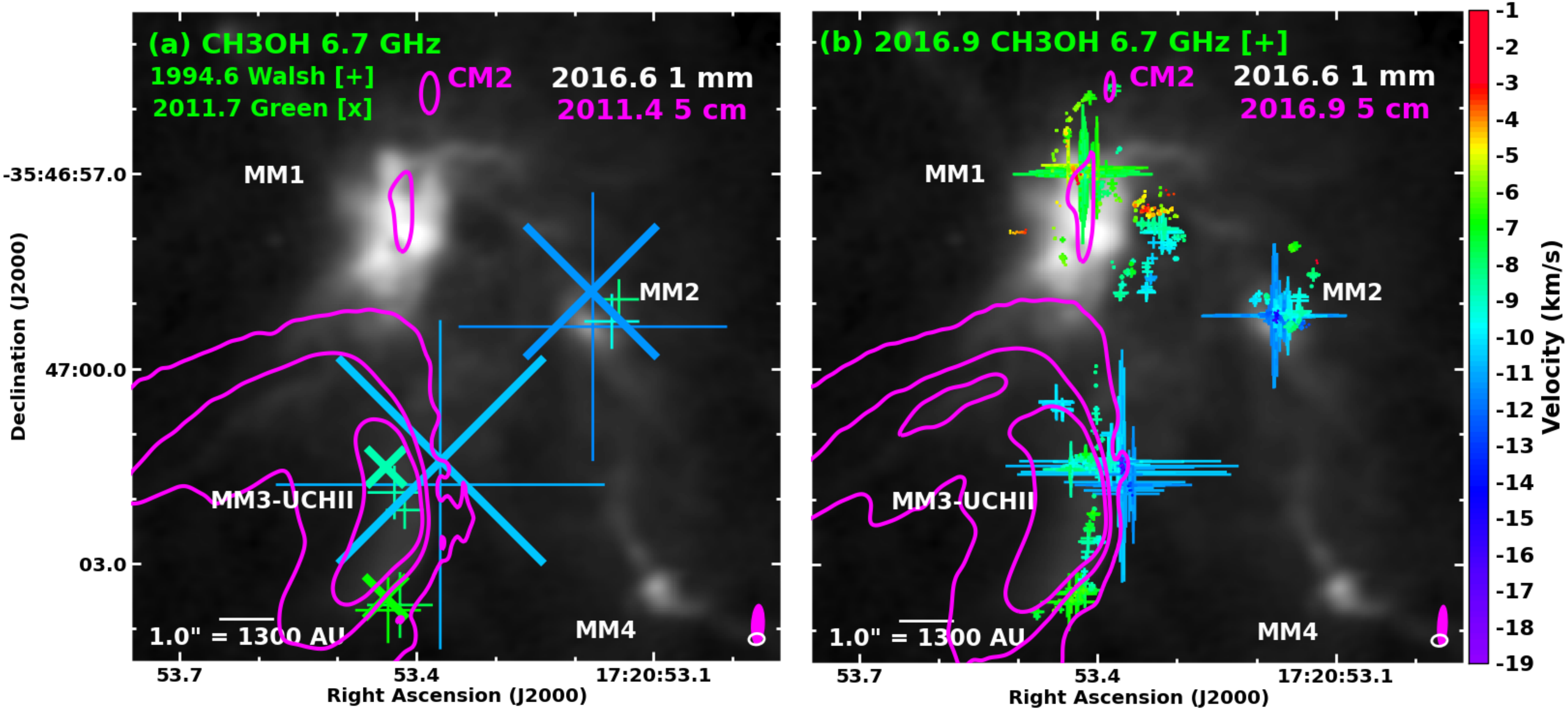
Hunter, Brogan et al. 2018, ApJ

Not seen here in 1988, 1992, 1994, 2005, 2011 ...

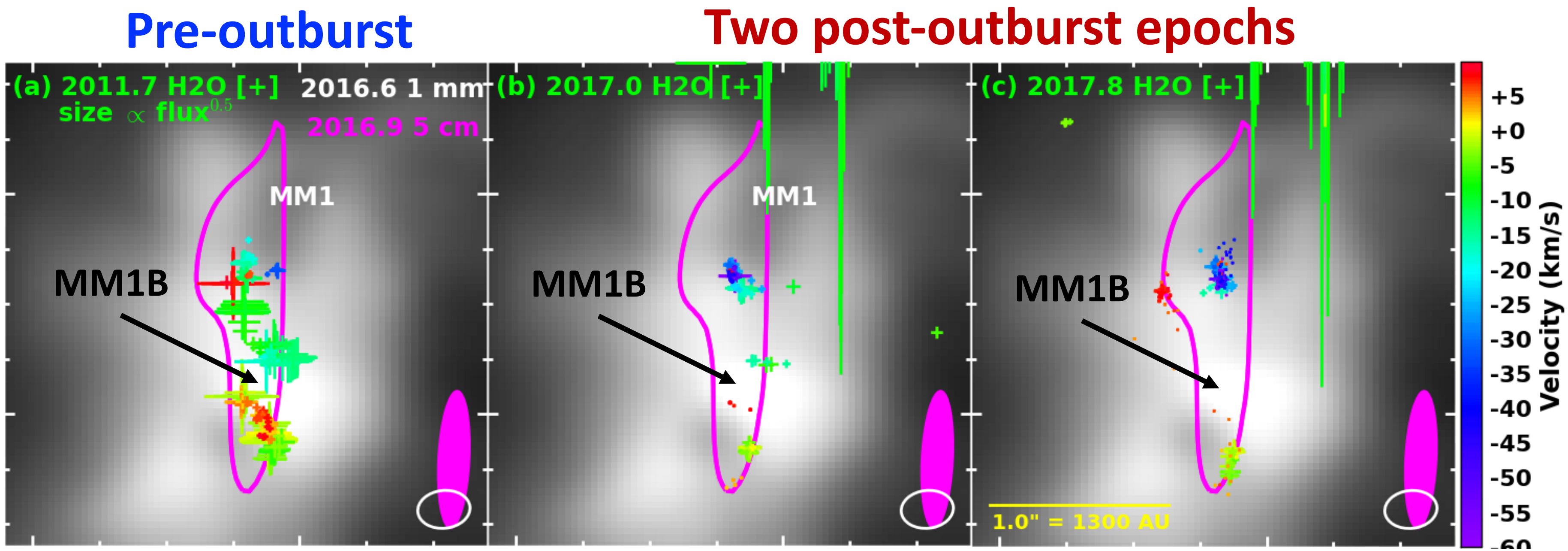
ATCA 1994 & 2011

Spot size $\propto \sqrt{\text{flux}}$

VLA 2016.9



# Water masers in MM1… destruction of many former groups



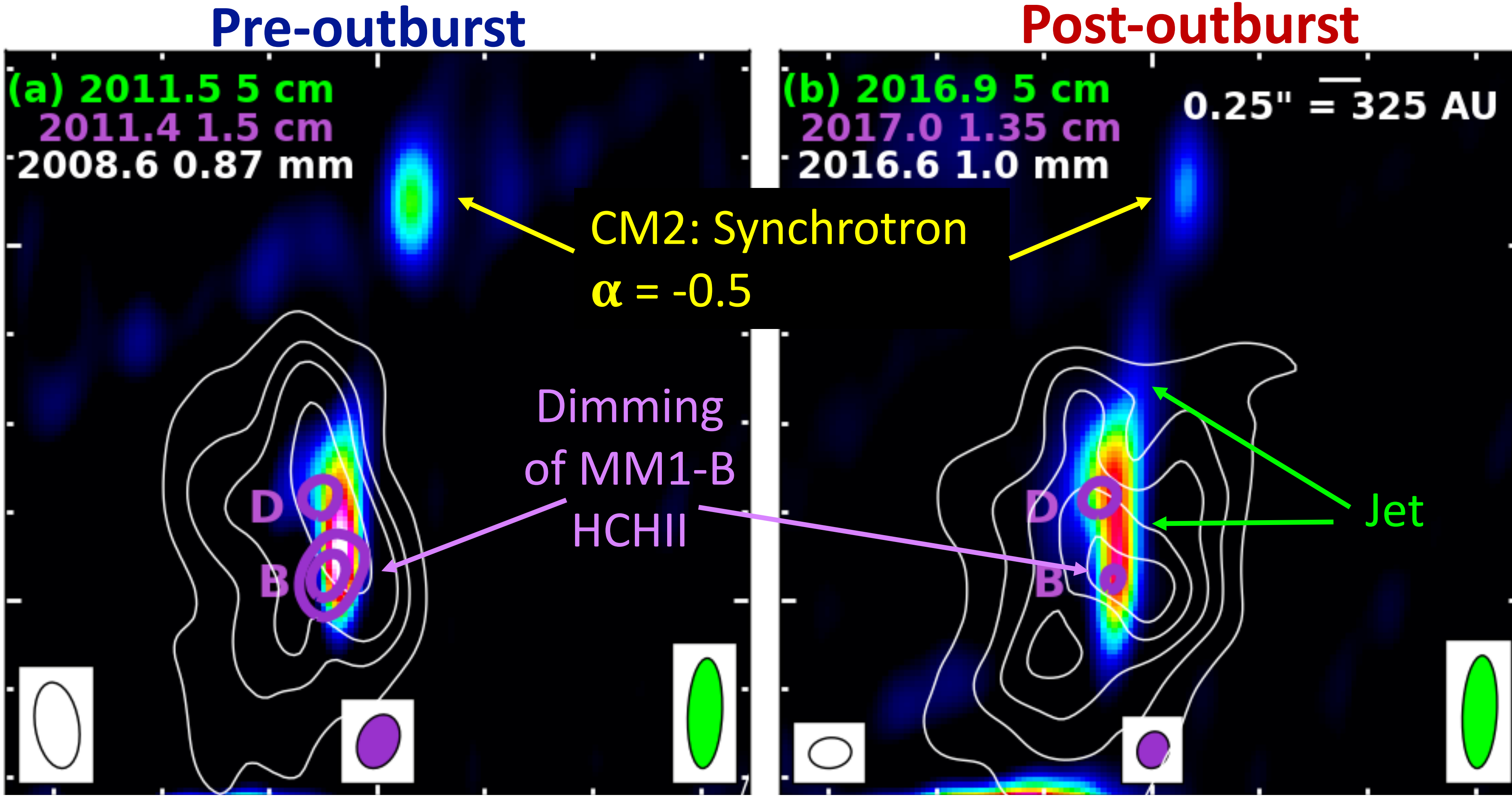

Flux density range 0.12 to 27 Jy

Flux density range 0.05 to 5.3 Jy

Water maser pumping models require hot gas and cooler dust
$\Rightarrow$ Dust temperatures now too high (post-outburst) for the maser pump to operate in vicinity of MM1B

**Brogan et al., in prep.**

# Evolution of free-free emission in MM1




See Simon Purser's talk on jets

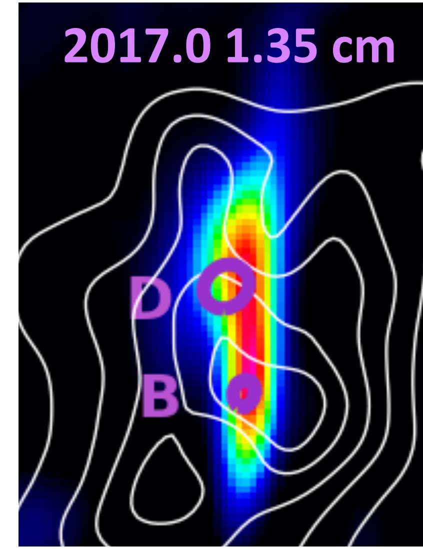
Brogan, Hunter+, in prep

# Dimming of HCHII region MM1B: Interpretation

**EPOCH 2017.0 1.35 cm:**

- MM1 D consistent with no change (± 10%)
- MM1 B has **dimmed** by a factor of 5.4 ± 0.5 → drop in uv photons

| Source | 1.5 cm 2011.4 (mJy) | 1.35 cm 2017.0 (mJy) |
|---|---|---|
| MM1 - D | 0.76 ± 0.1 | 0.73 ± 0.05 |
| MM1 - B | 1.78 ± 0.11 | 0.35 ± 0.03 |

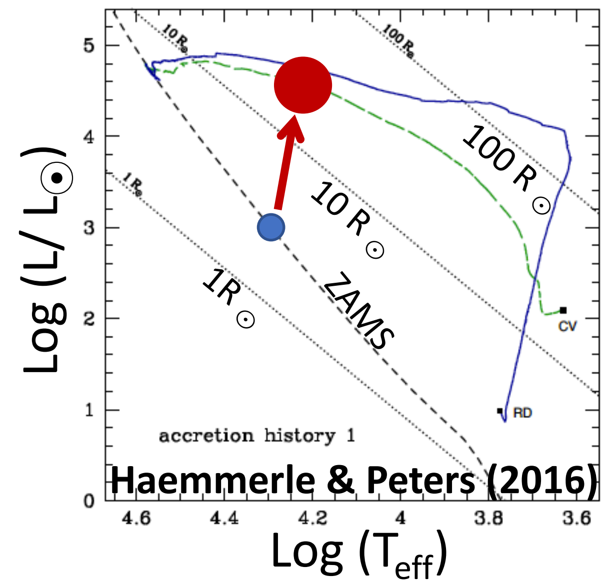



## Pre-outburst Star:

- 1.5 cm flux density → **B2 star** (ZAMS) with $\approx 10^3$ $L_\odot$ and 6 $M_\odot$ consistent with dust envelope $T_B$ lower limit: L > 600 $L_\odot$

## Post-outburst Star:

- 70x luminosity boost (mm Tb) implies $7 \cdot 10^4$ $L_\odot$ ($\approx 1/3$ $L_{Edd}$)
- cm dimming requires lower stellar $T_{eff}$, so radius must have expanded by 10x ($\approx$ 3.3 to 33 $R_\odot$) ⇒ **B3 supergiant**
- Similar bloating predicted by accretion models of:
  Hosokawa & Omukai (2009) for $\dot{M} = 10^{-3}$ $M_\odot$ yr $^{-1}$
  Haemmerle & Peters (2016) variable accretion models

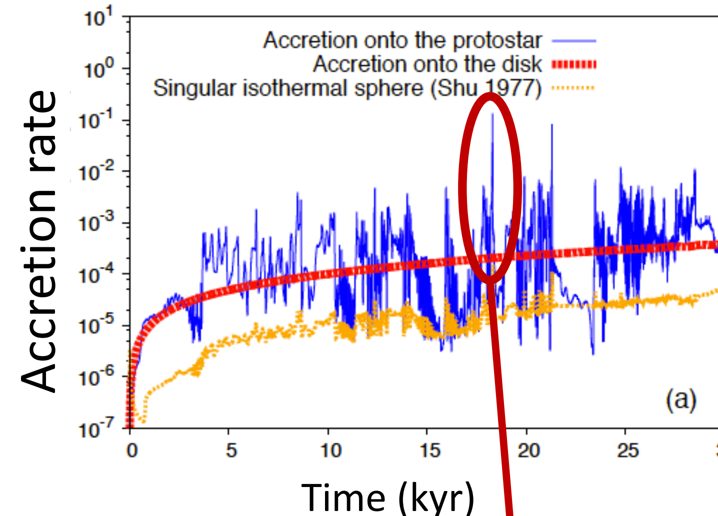


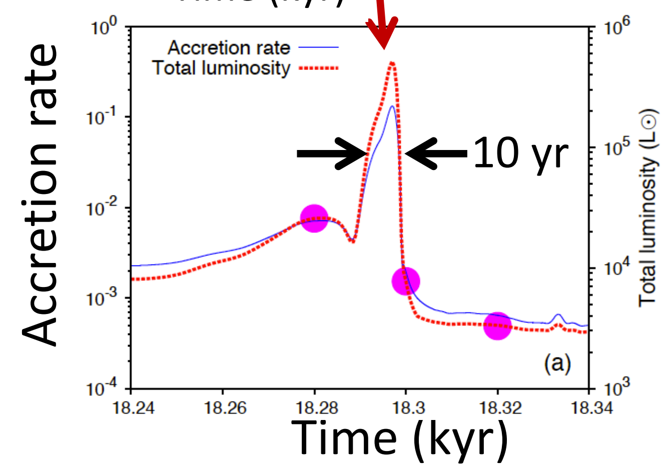
# Large accretion events are expected

**Meyer et al. 2017, 2018:** Numerical radiation hydrodynamic simulations, including gas self-gravity & radiative feedback

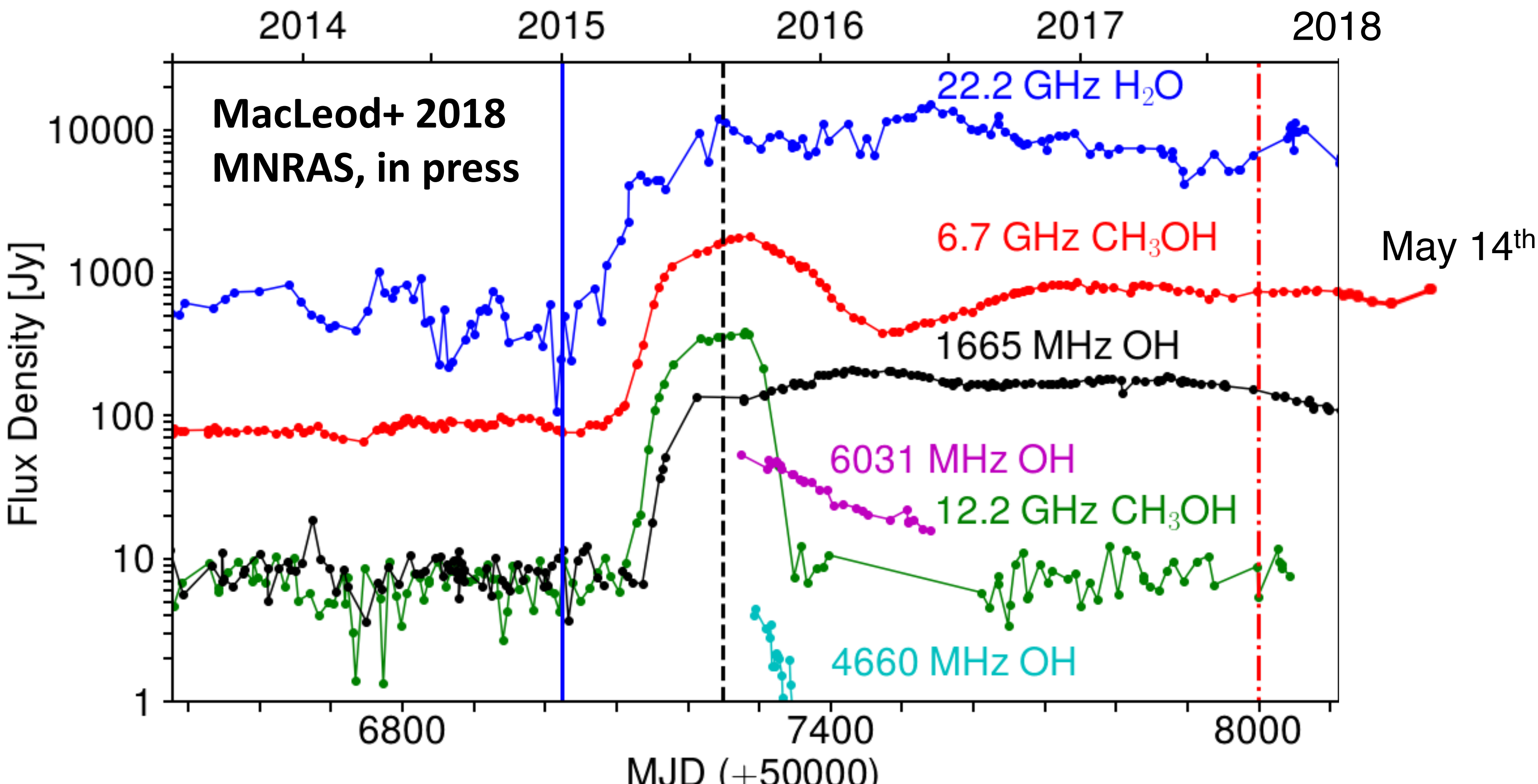
- Produces bursts in accretion rate up to 100x
  - Yields 50x boost in luminosity for ~10 yr
  - Large bursts separated by a few 1000
- **MM1 outburst of 70x is a rare event!**
  - Massive counterpart to an FU Ori event
- But smaller events are also expected….
  - e.g. **S255IR-NIRS3** flared in luminosity by 6x (Caratti o Garatti+ 2016) along with **$CH_3OH$ maser flare** (Fujisawa+ 2015, Moscadelli+ 2017) and increased jet emission 1 yr later (Cesaroni+ 2018)
- **$CH_3OH$ masers <u>can</u> be a probe of accretion rate!**

Large clump accreted.



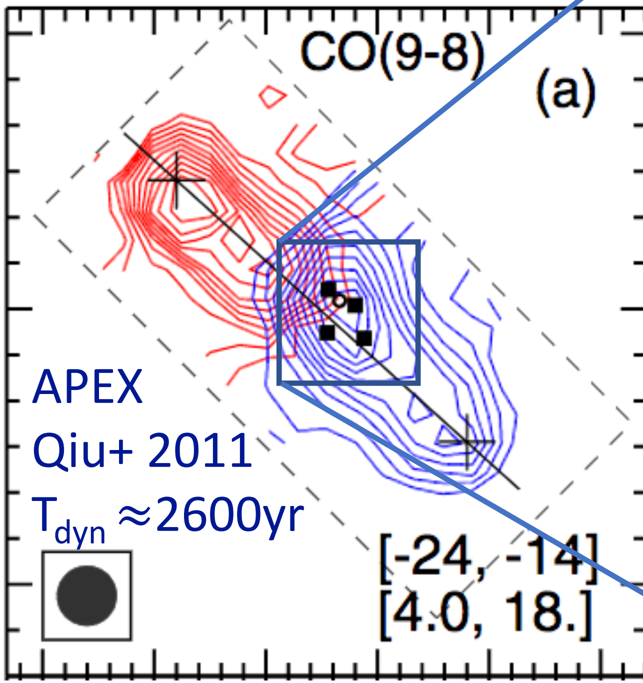



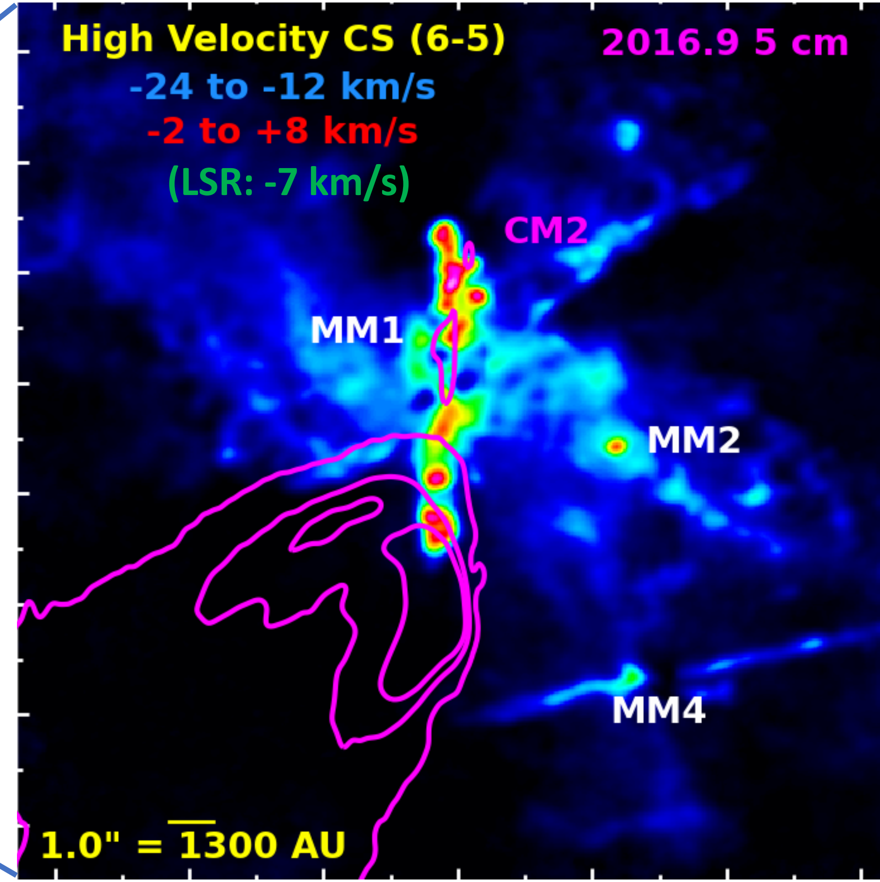
# Two Key Questions: (1) How long will the outburst last?
# (2) Is there a mediating disk?



# Copious Outflow Emission

Northeast – Southwest on 0.25 pc scale



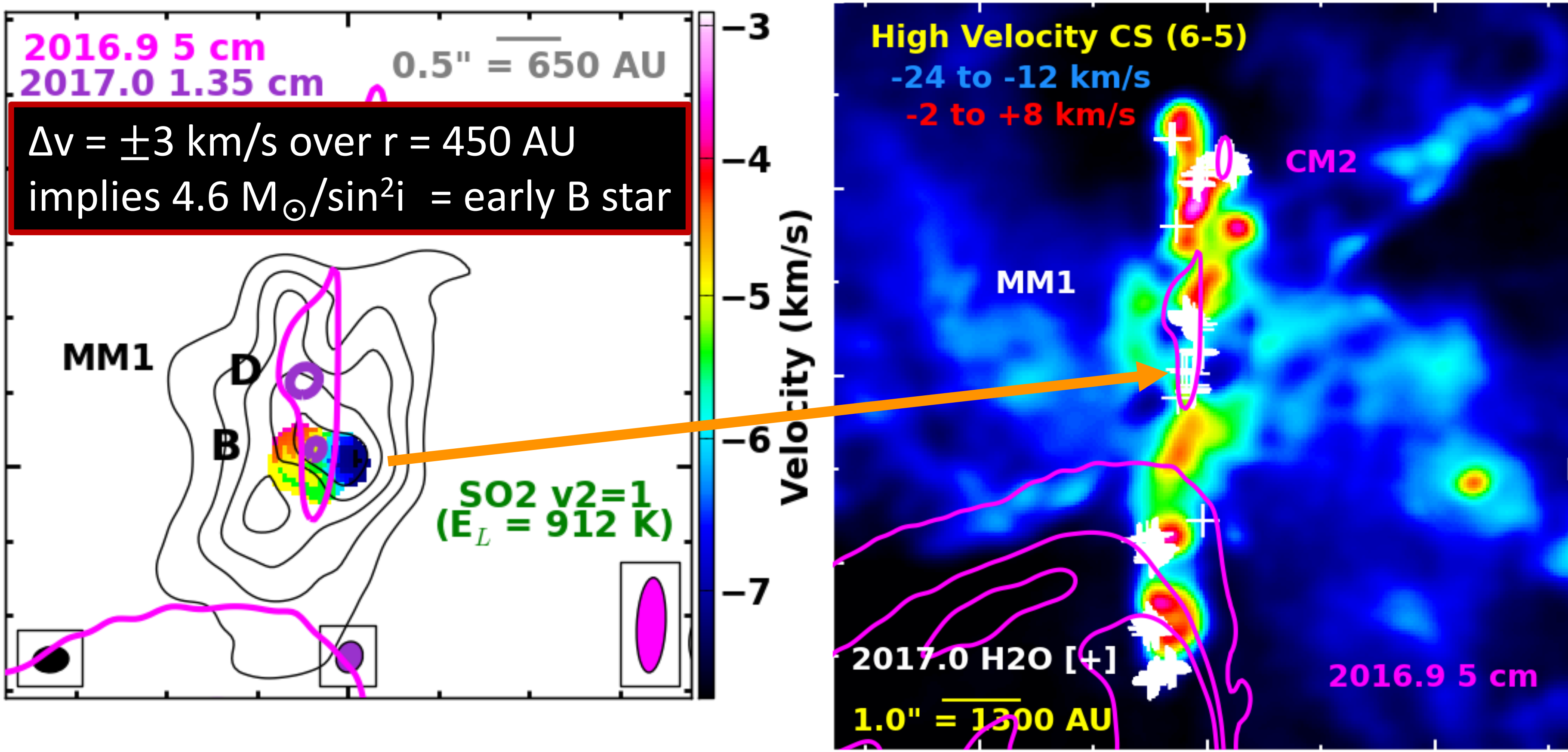




**Highly-collimated North–South Bipolar Molecular Outflow from MM1-B in CS 6-5**

Dynamical time ≈200-1000 yr (for i=80° to 45°), i.e. much younger than NE/SW flow.

New Pos.Angle vs. older flow suggests multi-directional accretion (W51; Goddi+ 2018)

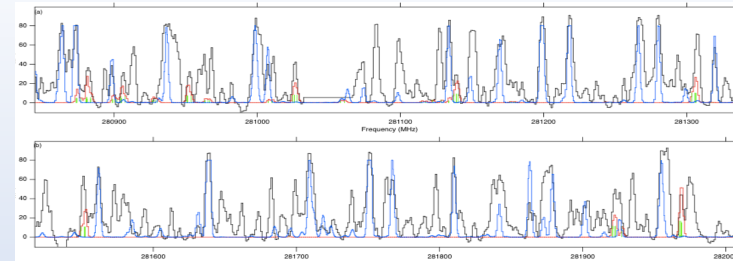
# The North–South Outflow Traced by Water Masers & ⊥ to MM1B Disk



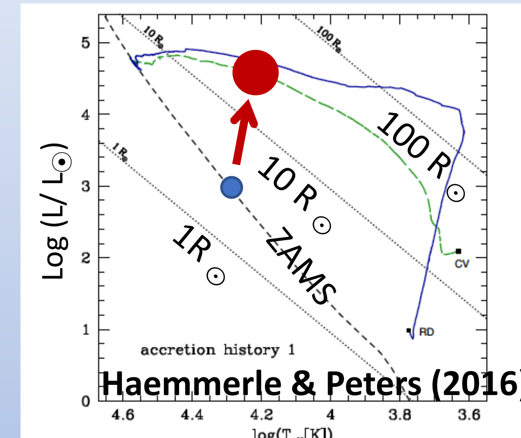

✓ Pre-evacuated outflow channel allows mid-IR to propagate (see Kuiper+ 2015; talk by A. Rosen; poster 36 by A. Kölligan+) and produce the water maser flares.

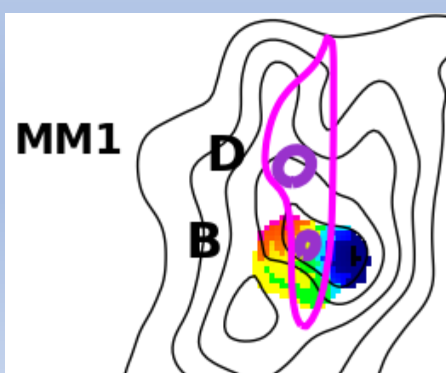
# Implications for Massive SF

- **One of the richest known hot core / maser sources is driven by a <u>mere</u> 6 $M_\odot$ protostar!**
  - Dust heats quickly, gas takes years (Johnstone+ 2013)
  - **Hot core = ``low-pass filter'' of outbursts? (Taquet+2016)**
    Frimann+17: sublimation radius in 20-50% YSOs too large for $L_{IR}$
- **Bloating may not be a single stage, but repeating**
  - Variability of other HCHII regions (Galvan-Madrid+ 2008)
  - **Observed FIR $L_{BOL}$ may severely overestimate mass of protostar**
  - Variable accretion models are important, e.g. Klassen+ 2012
- **Outburst-mediating disks are hot & compact**
  - Best probed by highly-excited lines in low ALMA bands (e.g. vibrationally-excited $SO_2$), to avoid the high dust opacity
  - **Radiative outbursts should help to stabilize a (growing) disk**



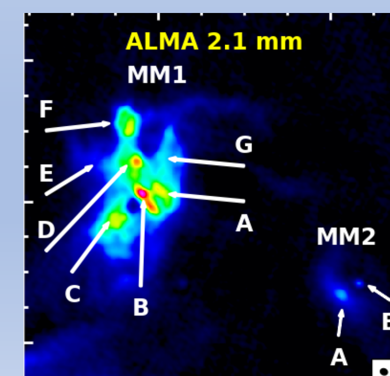
$CH_3OCH_2OH$ detection: McGuire+ 2017




**ALMA Cycle 6 Proposal 70 au resolution:**

1) Reach gravitational radius of HCHII region, resolve disk and measure its central mass
2) Monitor future variability and (eventually) motions within protocluster (Bands 4 and 6)

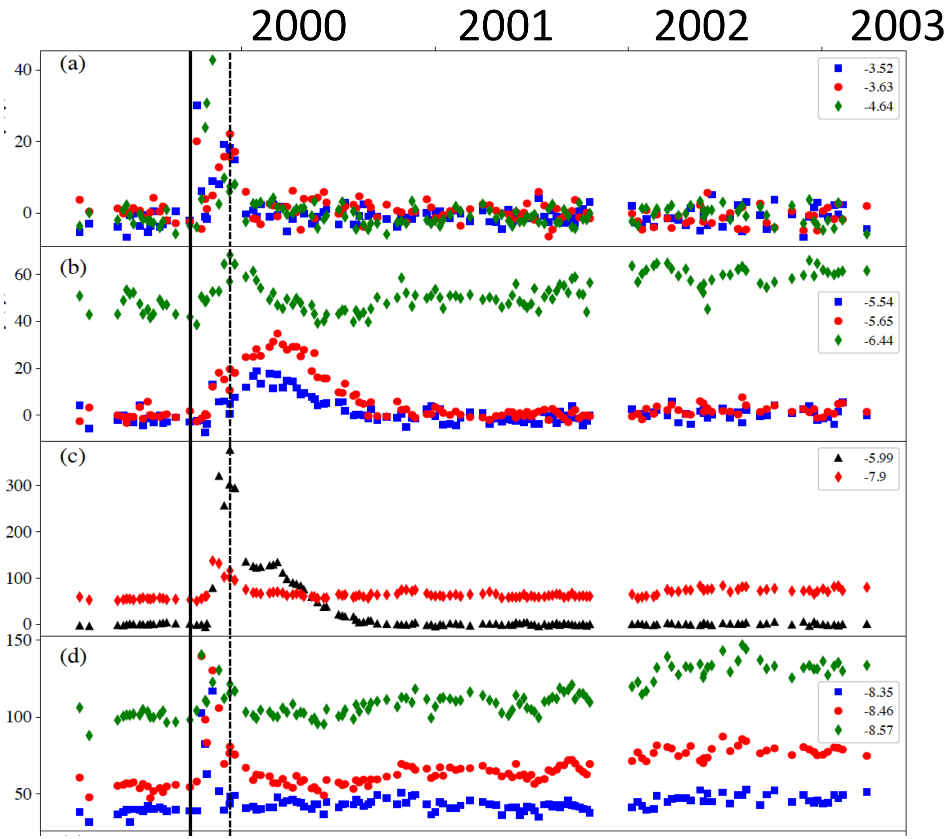



T. Hunter 2018-05-29

# Extra slides

# A smaller event in NGC6334I: Dec. 1999 maser "mini-burst"

- -5.9 km/s $CH_3OH$ maser component went to >100 Jy for 6 months (Goedhart+2004)
- -5.9 km/s in 2016.9 cube is on MM1 (7.7 Jy)
- **A pre-cursor or a recurring phenomenon?**




**MacLeod et al. 2018 MNRAS, in press**
Speculate that 3 known outbursts can be fit by decaying orbit of a binary system embedded in gas (Stahler 2000). More of clump being accreting on each passage?