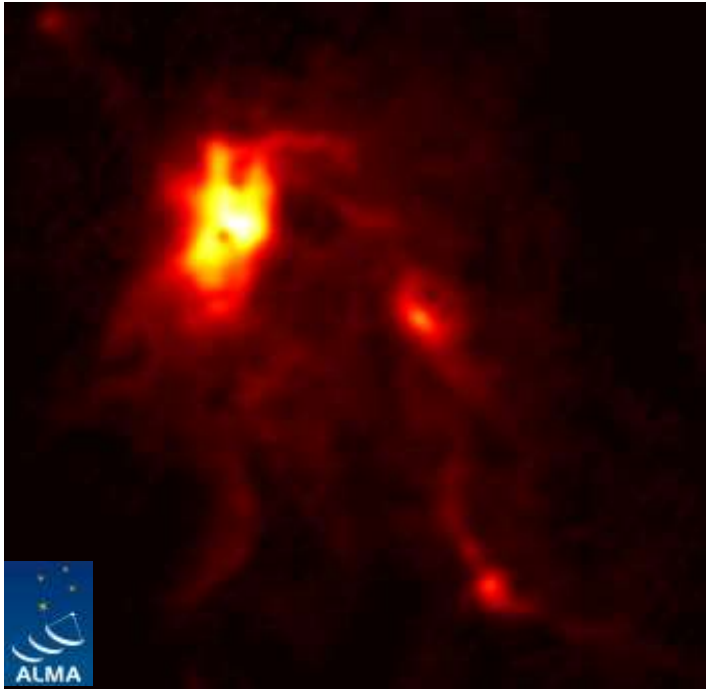
The Extraordinary Outburst in NGC6334I-MM1: Dimming of the Hypercompact HII Region and Destruction of Water Masers



1 mm ALMA image of NGC6334I - 200 AU resolution

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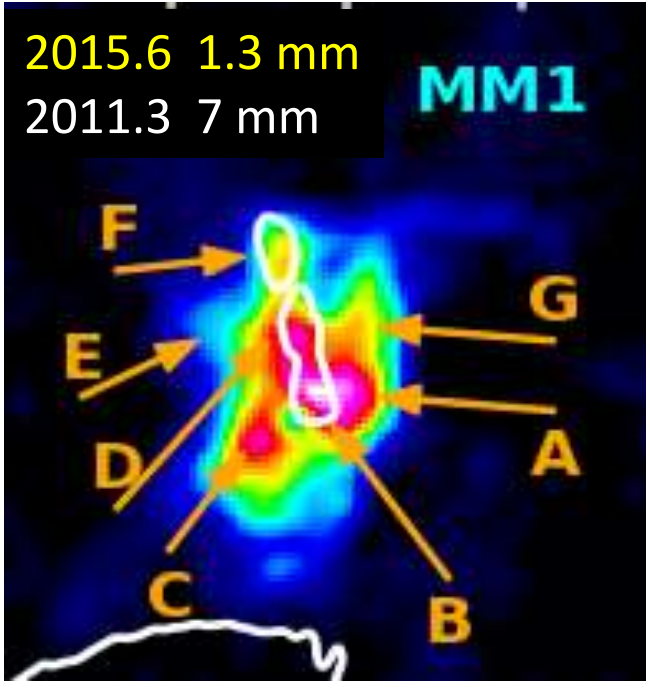
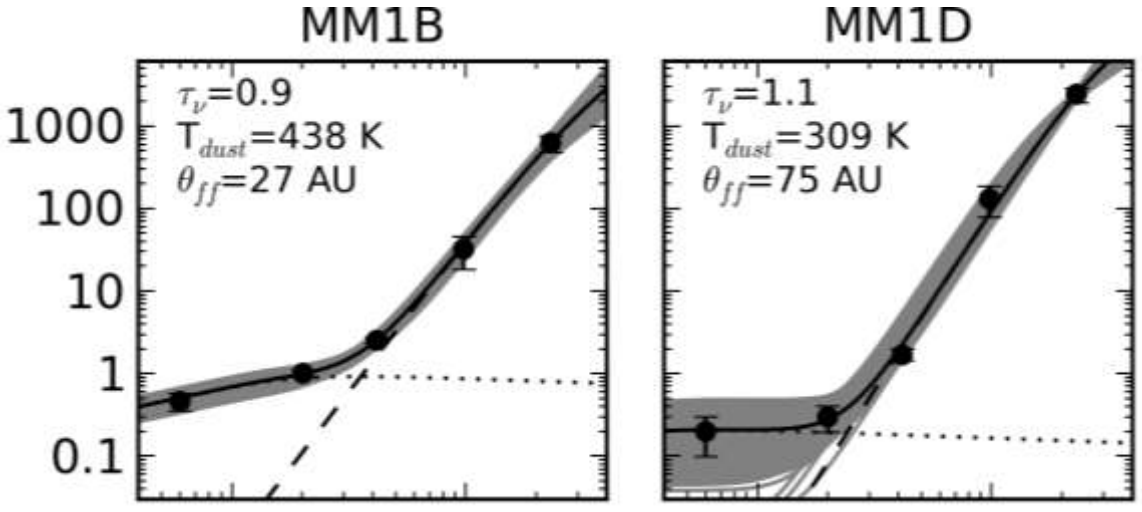
IAU Symposium 336: Astrophysical Masers: Unlocking the Mysteries of the Universe; Cagliari, Italy; September 4-8, 2017

NGC6334 I-MM1: Dust and free-free emission





MM1 dust sources B and D show free-free emission:

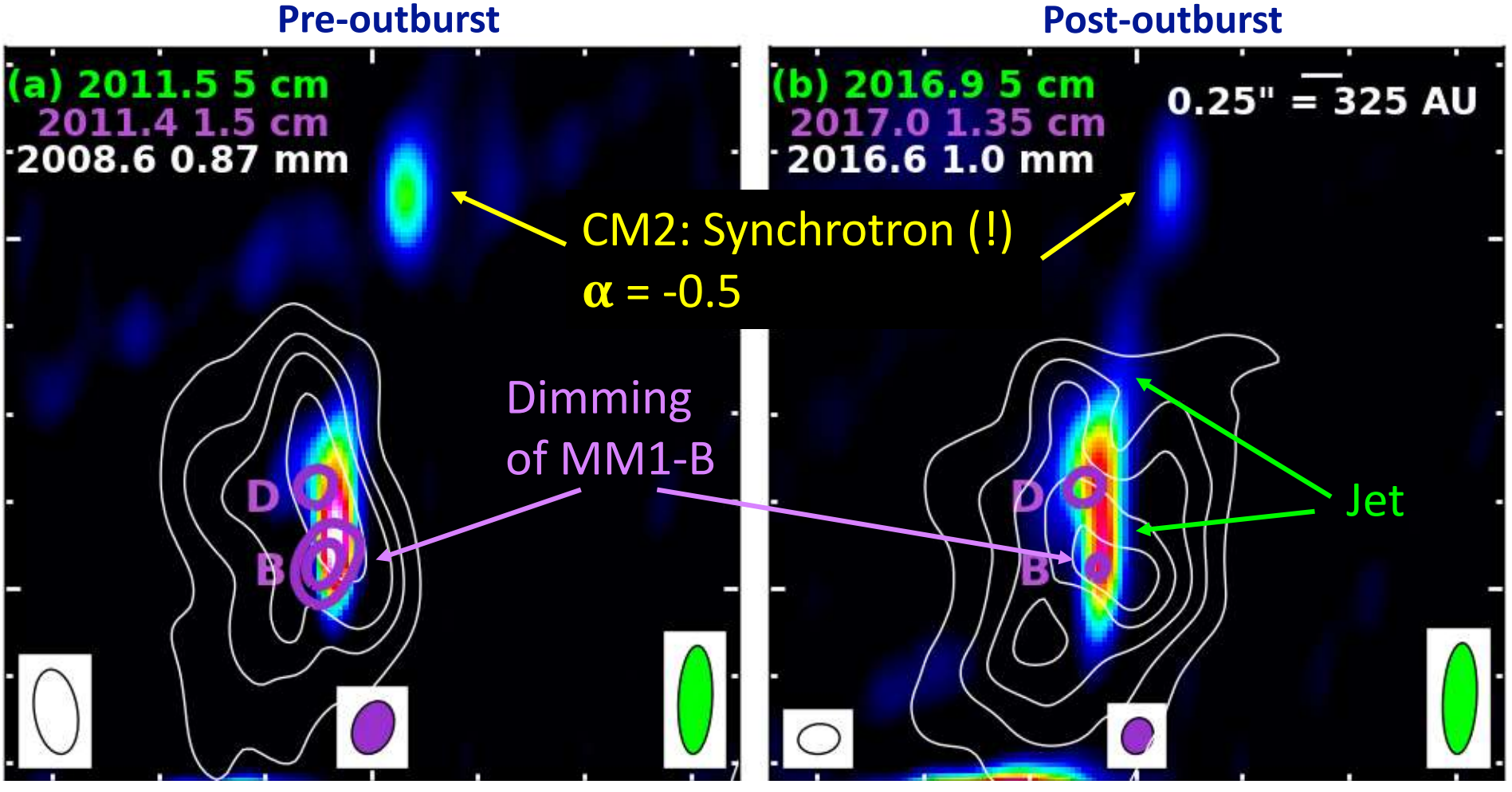
B: Modeled as Hypercompact HII region (n_e=3x10^6 cm^{-3}), high turnover frequency; hottest dust (440 K)

D: 300K dust plus jet (n_e=3x10^5 cm^{-3})

But… if the millimeter emission flared in early 2015 what about the centimeter wavelength emission?

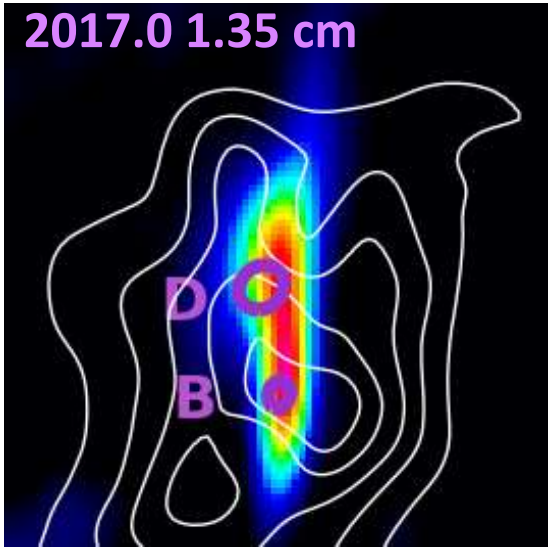
Brogan, Hunter+ 2016, ApJ

Evolution of free-free emission in MM1 (D = 1.3 kpc)



Dimming of HCHII region MM1 - B

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



2017.0 1.35 cm emission:

- MM1 – D consistent with no change (to within 10%)
- MM1 – B has **dimmed** by a factor of 5.4

Pre-burst:

- 1.5 cm emission is equivalent to a ZAMS B2 star with 1300 $L_{\odot}$ (Todd's talk)

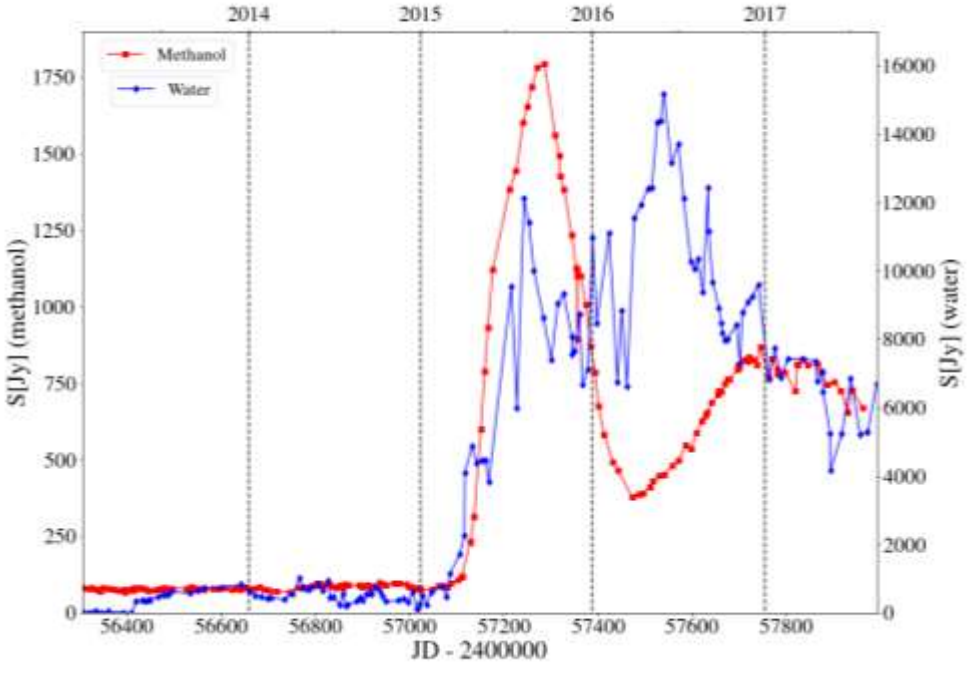
Post-burst:

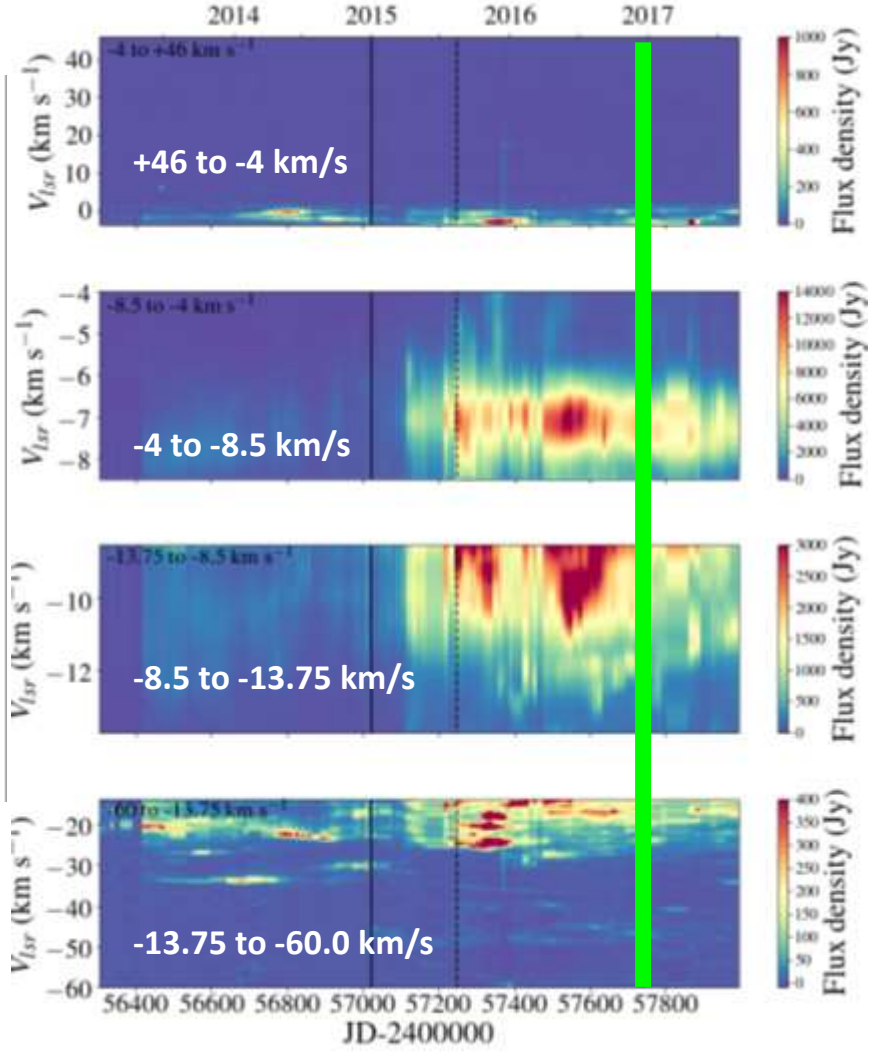
- 70 x luminosity increase (mm Tb increase) 90,000 $L_{\odot}$
- 1.35 cm dimming requires lower effective stellar temperature and hence a larger radius by factor of 10 (33 $R_{\odot}$) ⇒ B3 supergiant
- Level of bloating predicted by accretion models of Hosokawa & Omukai 2009 & Inayoshi+2013 for 10^{-3} $M_{\odot}$ per year

Hope to get another epoch in upcoming JVLA B-configuration(mid-Sept to end-Jan)

Water Masers Also Flared... Complex kinematics

-7.2 km/s Methanol & Water over time





HartRAO 26m

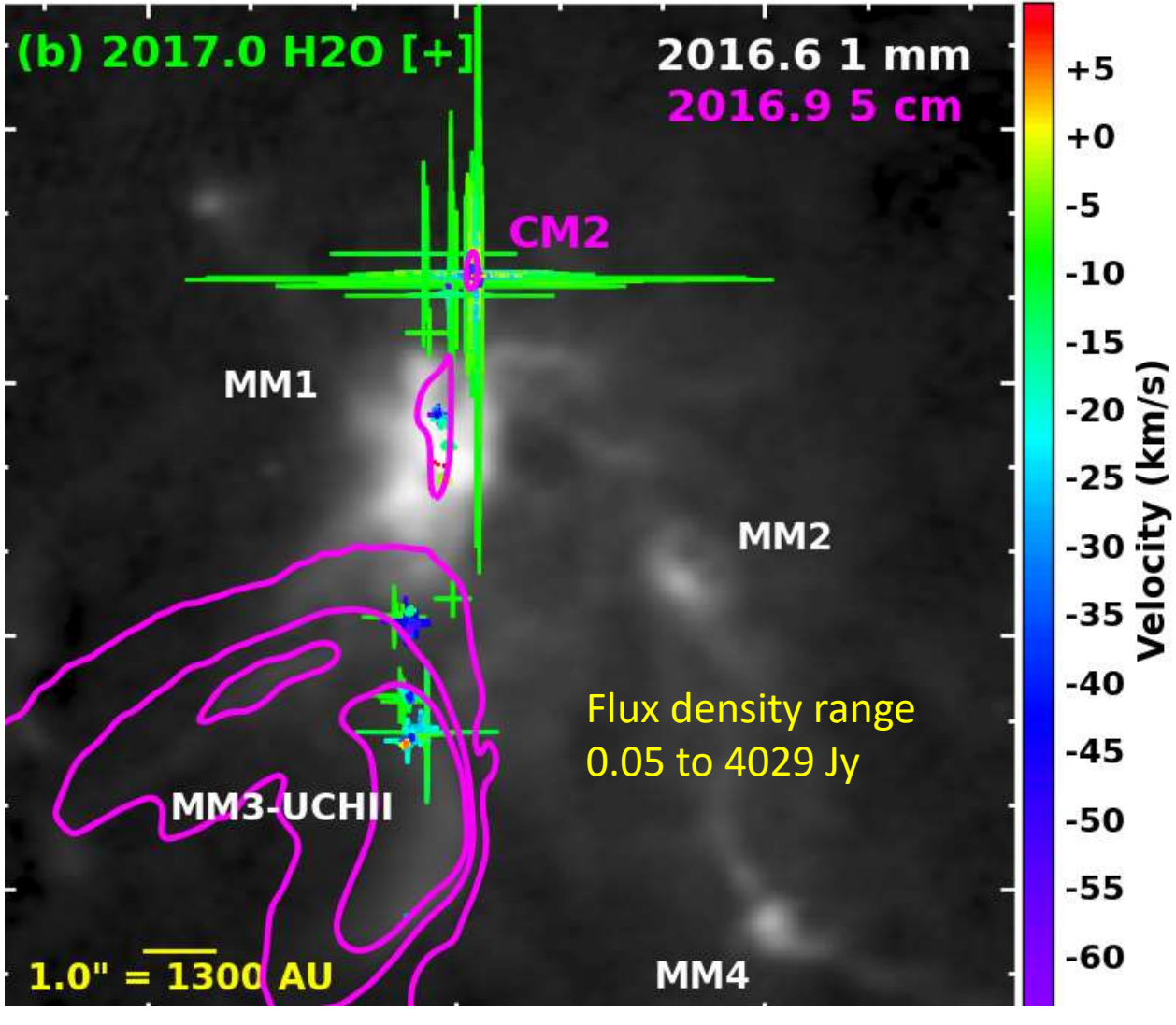
MacLeod et al. in prep. (Poster #21)

Where are the Post-Outburst Water Masers?

Hunter, Brogan et al. (2017, in prep)

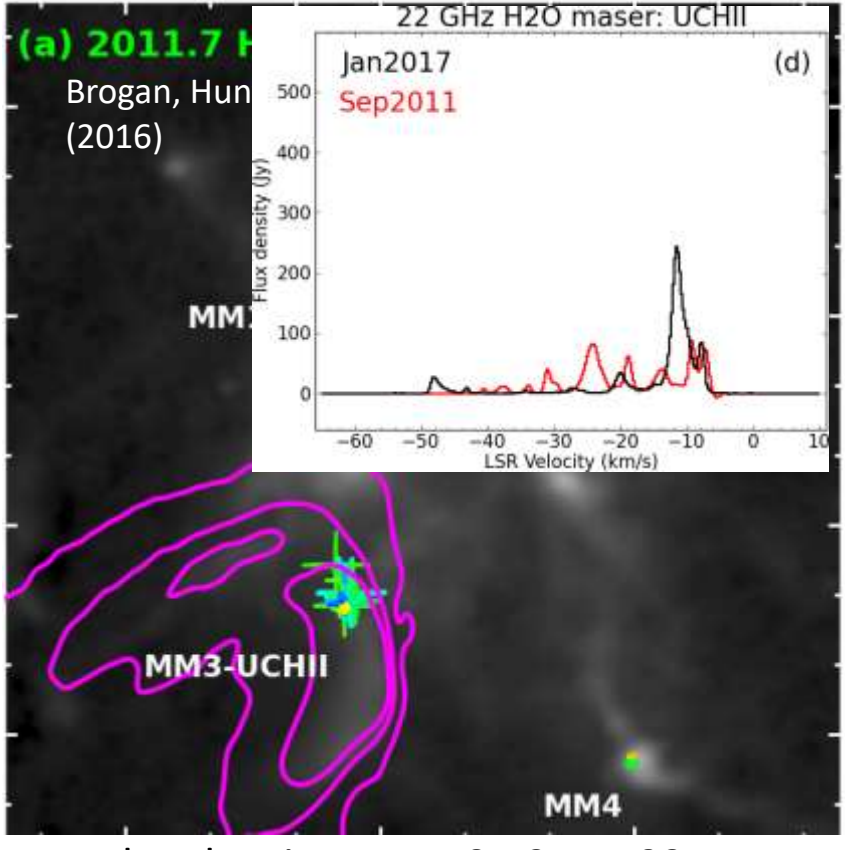
JVLA A-config.
0.2” resolution
at epoch 2017.0

- Spot size proportional to (flux density)$^{0.5}$
- Strongest emission near CM2
- Weak emission toward MM1
- Also several groups toward MM3 – UCHII, but East of ionization boundary



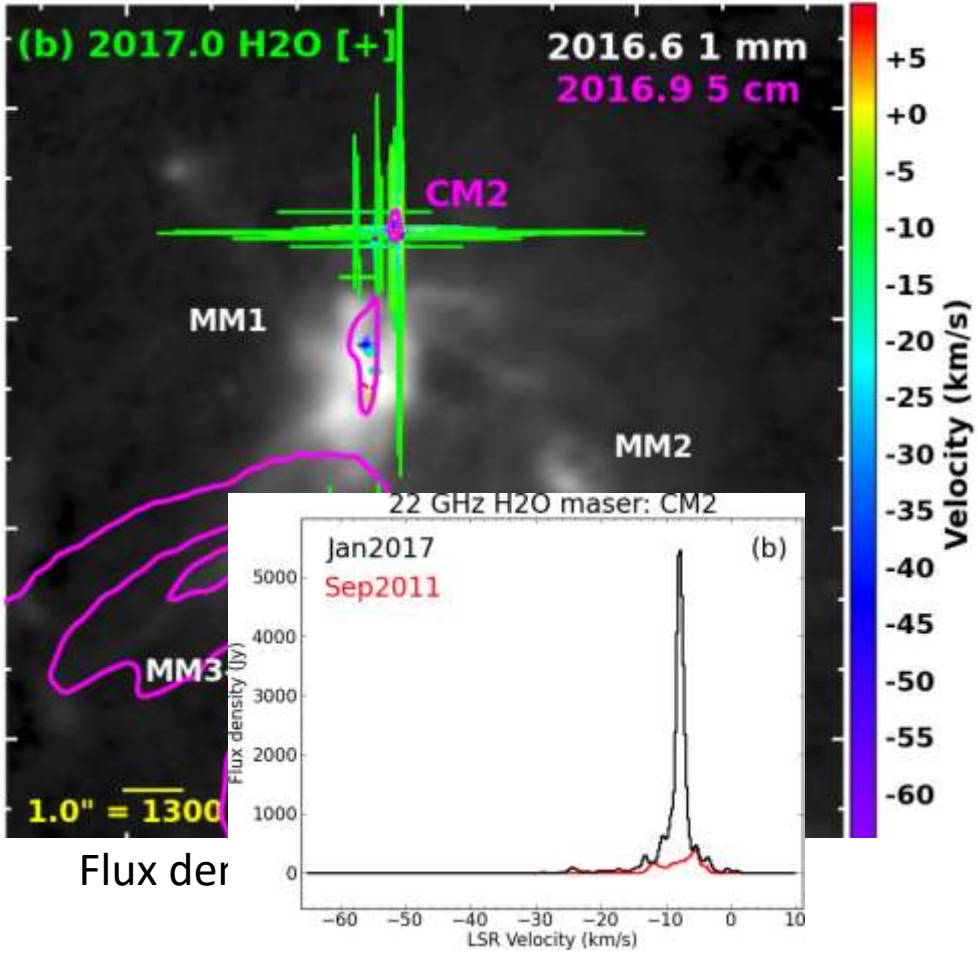
Evolution of Water Maser Emission

Pre-outburst



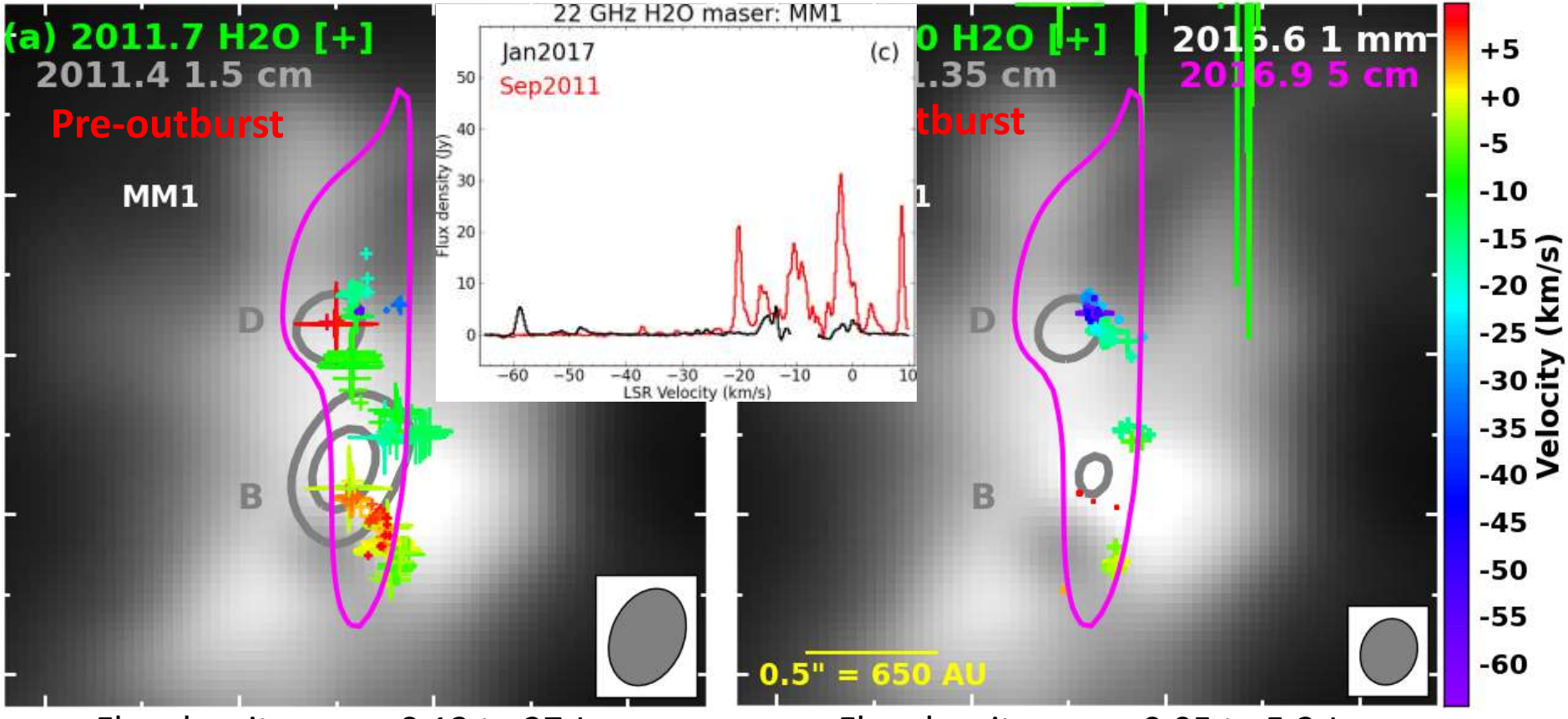
Flux density range 0.12 to 493 Jy

Post-outburst



Flux der

Zoom to MM1… destruction of many former maser groups

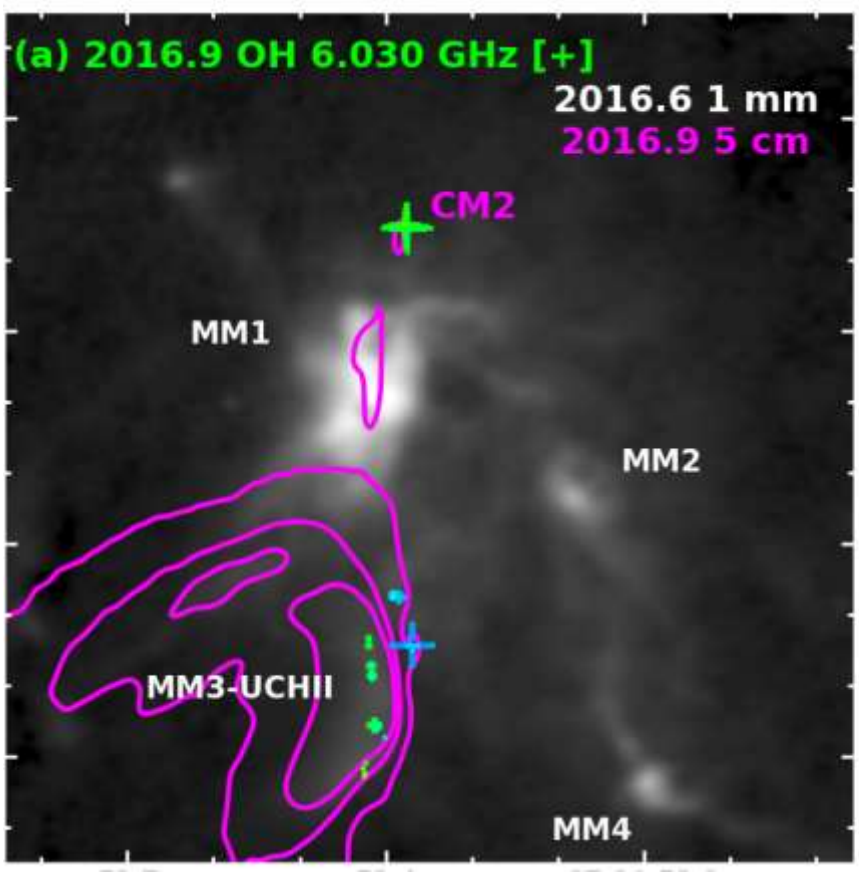


Flux density range 0.12 to 27 Jy

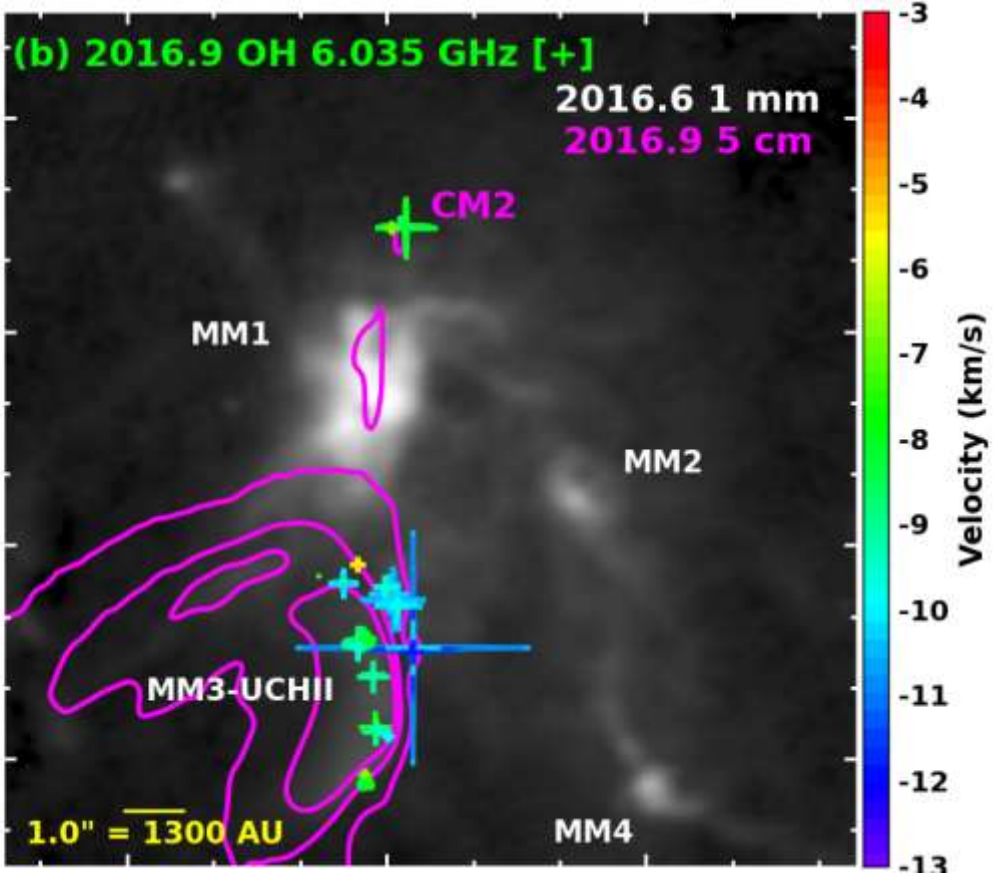
Flux density range 0.05 to 5.3 Jy

⇒ Dust temperatures too hot post-outburst for pump in vicinity of MM1-B?

6 cm Excited OH masers (two transitions) Post-Outburst:



Flux density range 0.011 to 8 Jy

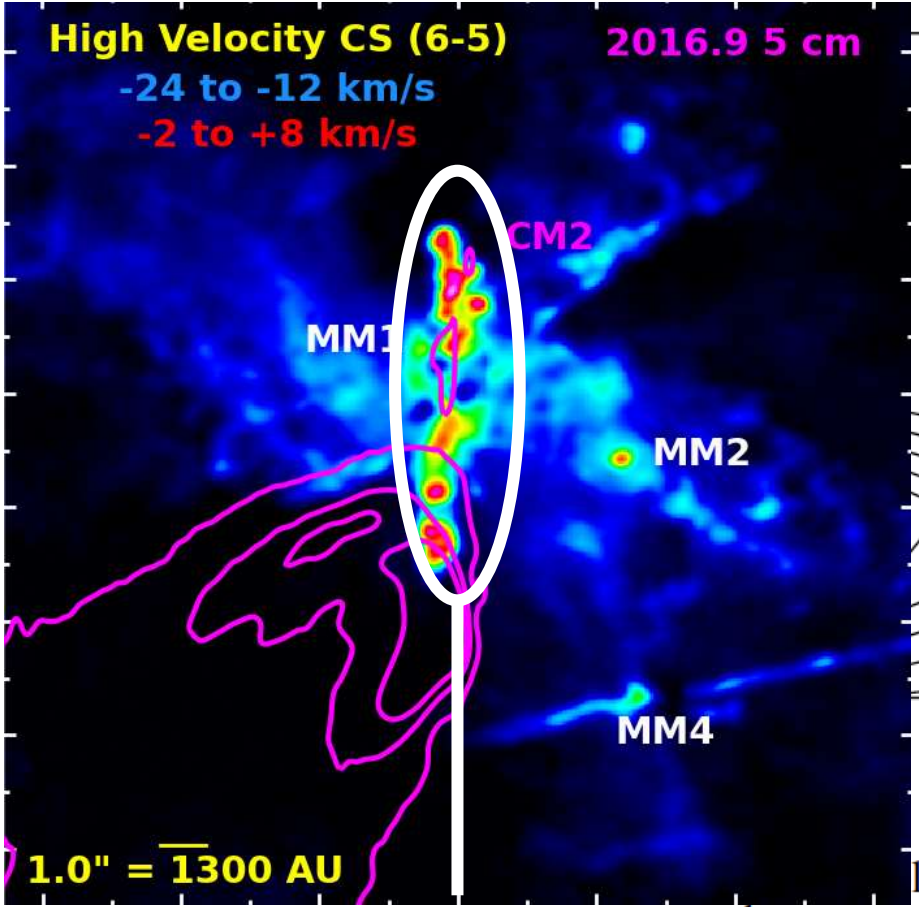


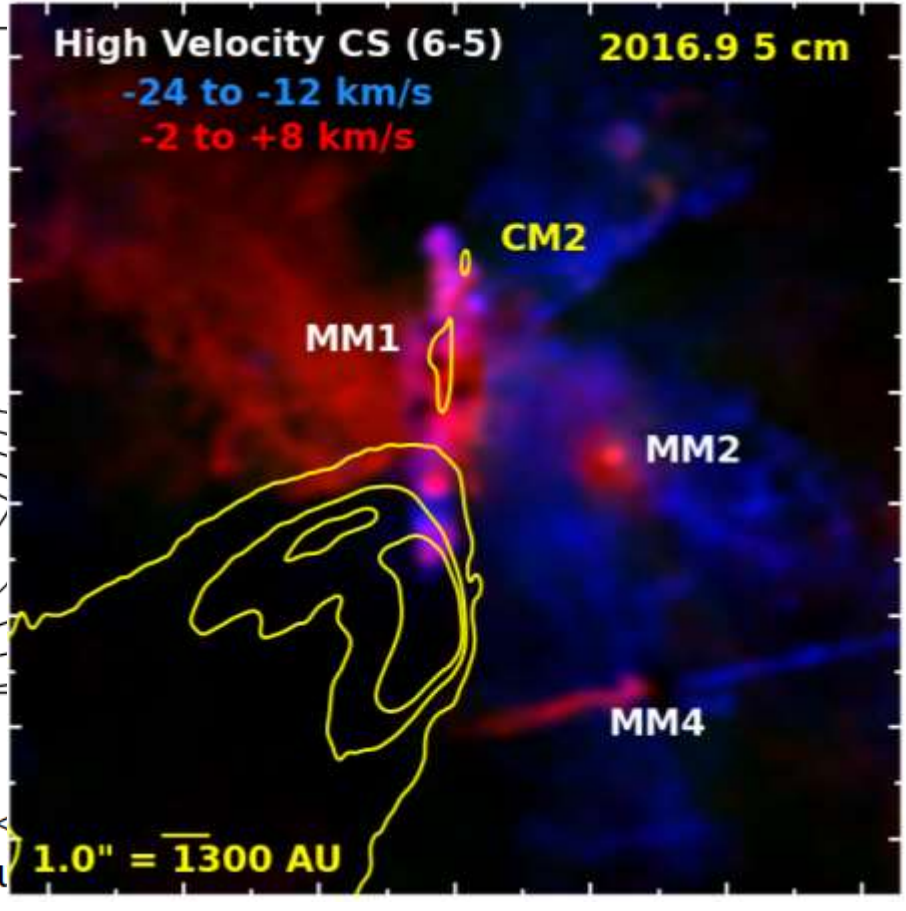
Flux density range 0.011 to 168 Jy

Components toward CM2 are new (see for example Caswell 2011)

Copious Outflow Emission (LSR ~ -7 km/s)

Brogan, Hunter et al. in prep.

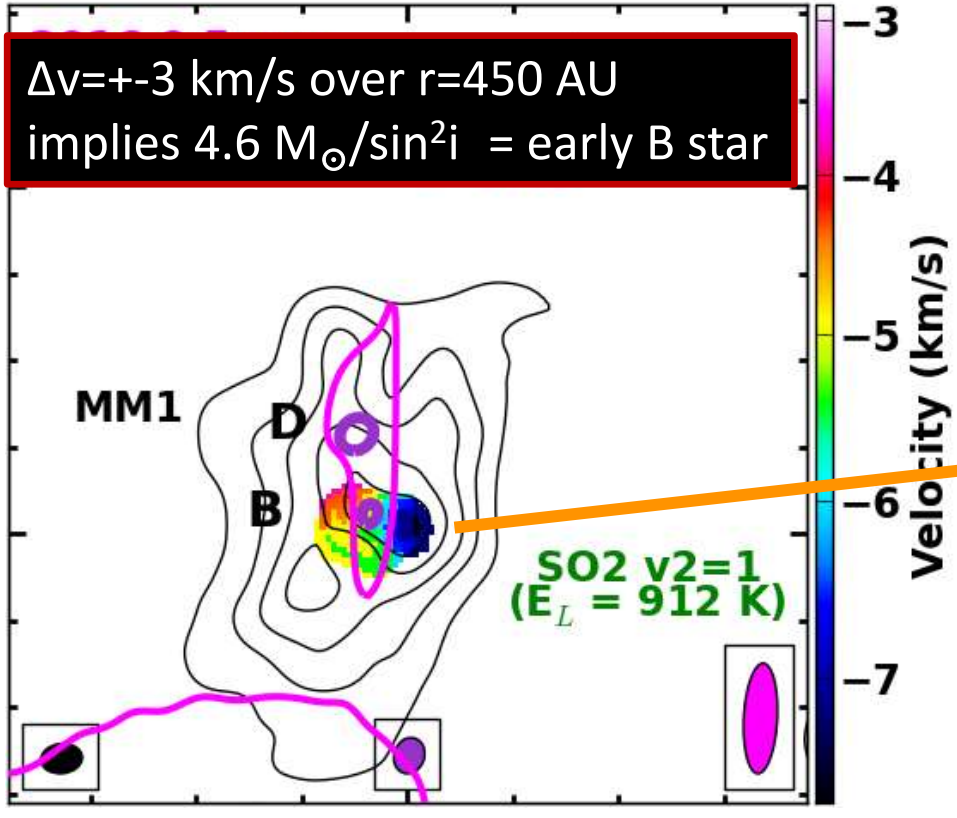


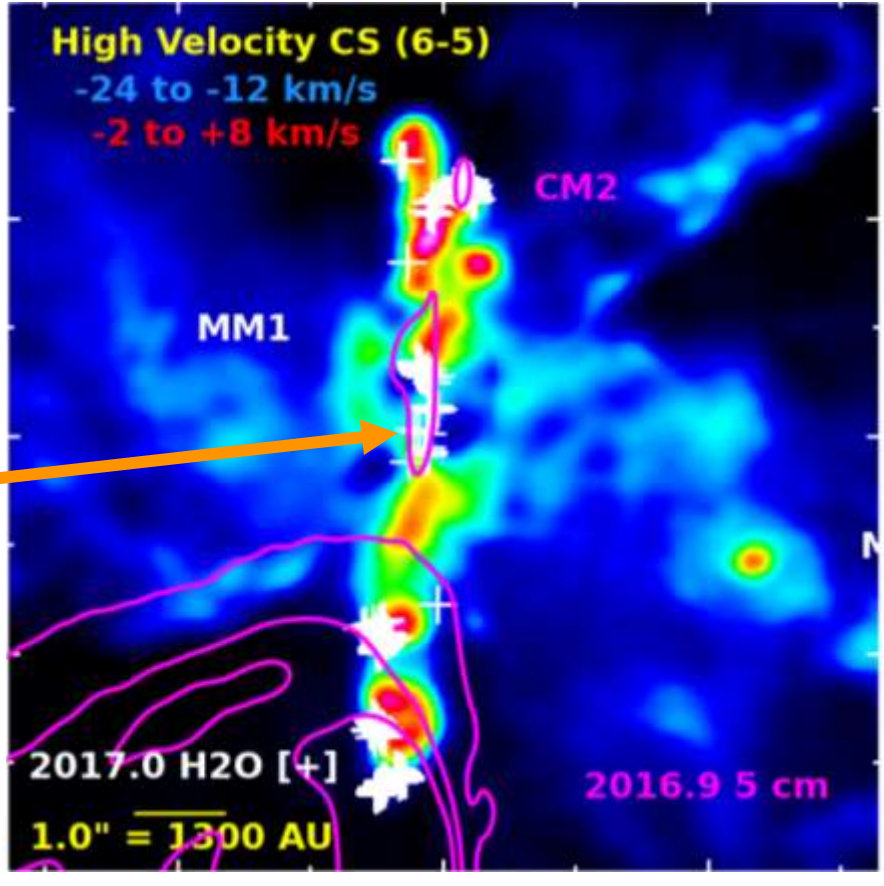


Highly Collimated North – South Outflow from MM1-B

Dynamical time ~ 200 to 1000 years (depending on inclination: 80 to 45 degrees)

The N – S Outflow Traced by Water Masers & ⊥ to MM1B Disk





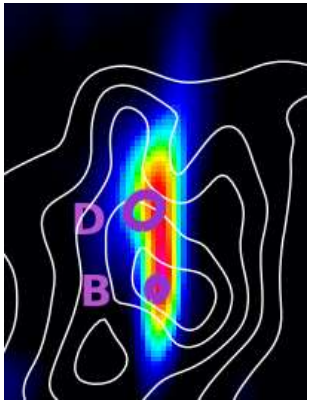
- ✓ ALMA Cycle 4 project optimized for disk study with 2.5x better angular resolution
- • ALMA Cycle 5 project optimized to better study outflows including multi-transition SiO

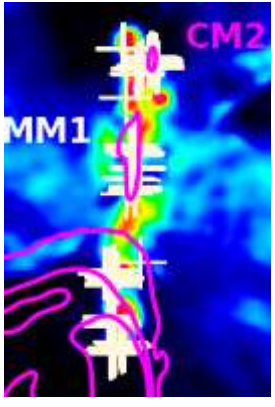
Summary

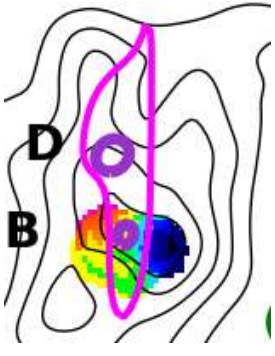
The remarkable outburst from HCHII MM1 – B

- Dimming of free-free emission by factor of 5.4
  - Cooling and bloating star to supergiant size in agreement with predictions of accretion models
- Water masers
  - Number and intensity greatly reduced in the vicinity of MM1 – dust temperature too hot post-outburst to sustain pump?
  - Flare towards CM2, as well as excited OH (what the heck is CM2???)
- Highly collimated, young N-S outflow traced by CS (6-5)
  - Along same axis as 5 cm jet
  - Northern terminus at mysterious, synchrotron centimeter source CM2
  - Remarkable correlation with water masers, including those previously thought to be associated with MM3 - UCHII
  - Velocity gradient perpendicular to N-S outflow in highly excited lines (vibrational SO2), consistent with ~ 5 $M_{\odot}$

Monitoring and investigations continue….



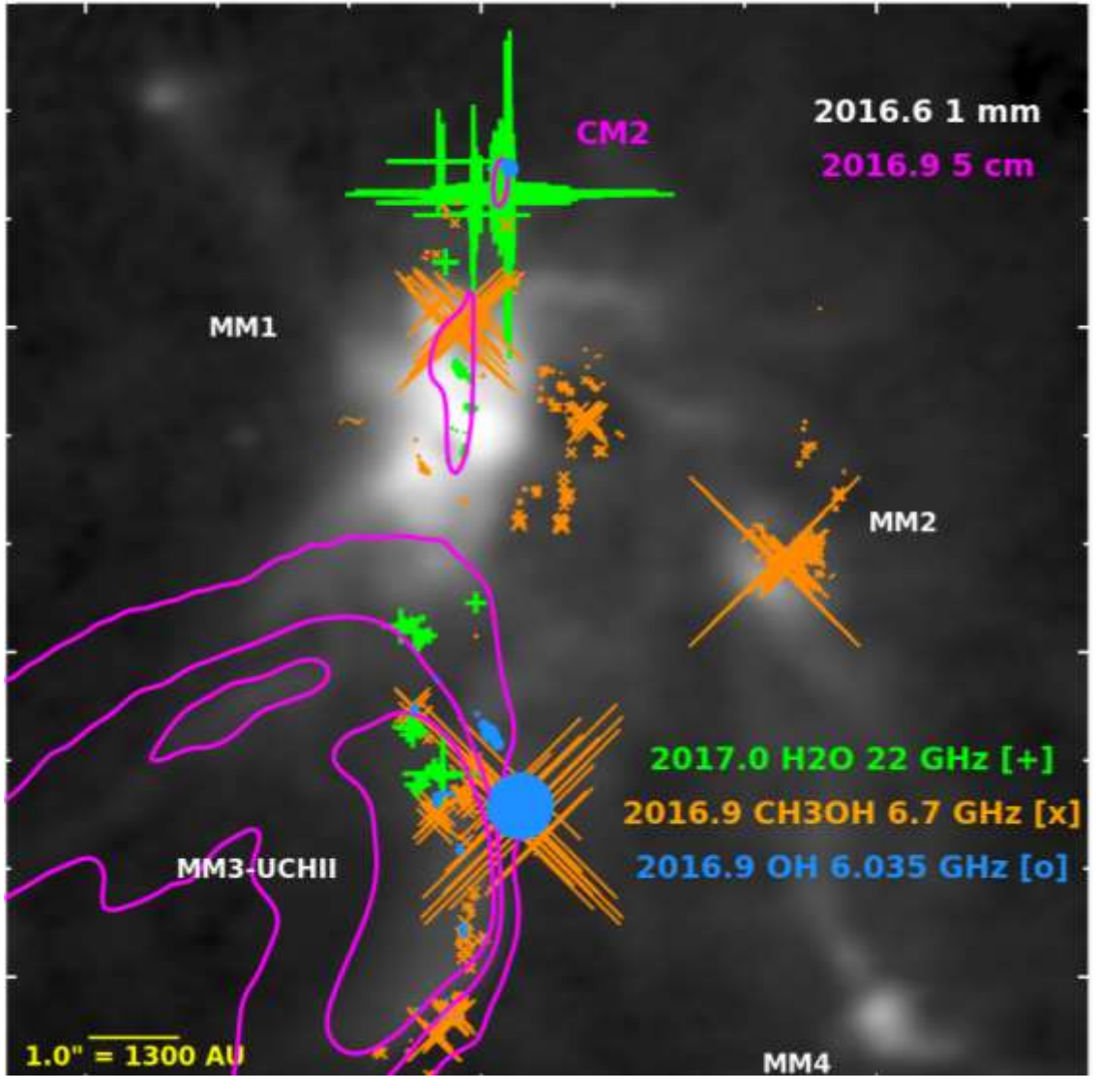




Extra slides

Epoch 2016.9 – 2017.0 Masers Together

- 6.7 GHz CH3OH is NOT always associated with a protostar
- H2O associated with highly collimated, dynamically young outflow 8000 au in length.
- Excited OH associated with H2O (CM2) at northern extreme of N-S outflow **and** CH3OH toward MM3-UCHII



Accretion as luminosity source: yes!, but in what form?

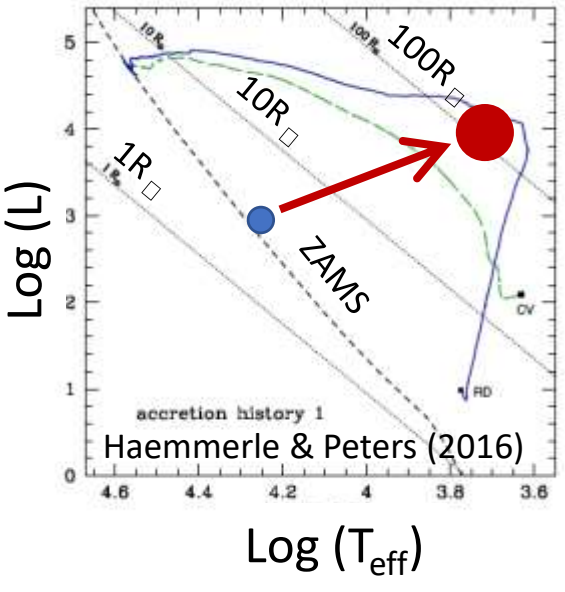
Case 1: "Disk-mediation":
a 0.1 $M_{\odot}$ gas fragment is absorbed by disk then drains onto $5M_{\odot}/3R_{\odot}$ protostar over **100 years** at $\dot{M}=10^{-3}$ $M_{\odot}/yr$:

$$L_{acc}=GM\dot{M}/R = 0.24\ L_{edd}$$

Case 2: "Direct accretion": gas fragment hits protostar, creating a shock which leads to a cooler photosphere at a larger radius (dropping the UV flux) and cools radiatively for Kelvin-Helmholtz time: GMM_{*}/RL ~ **a few yrs** (depending on initial radius)



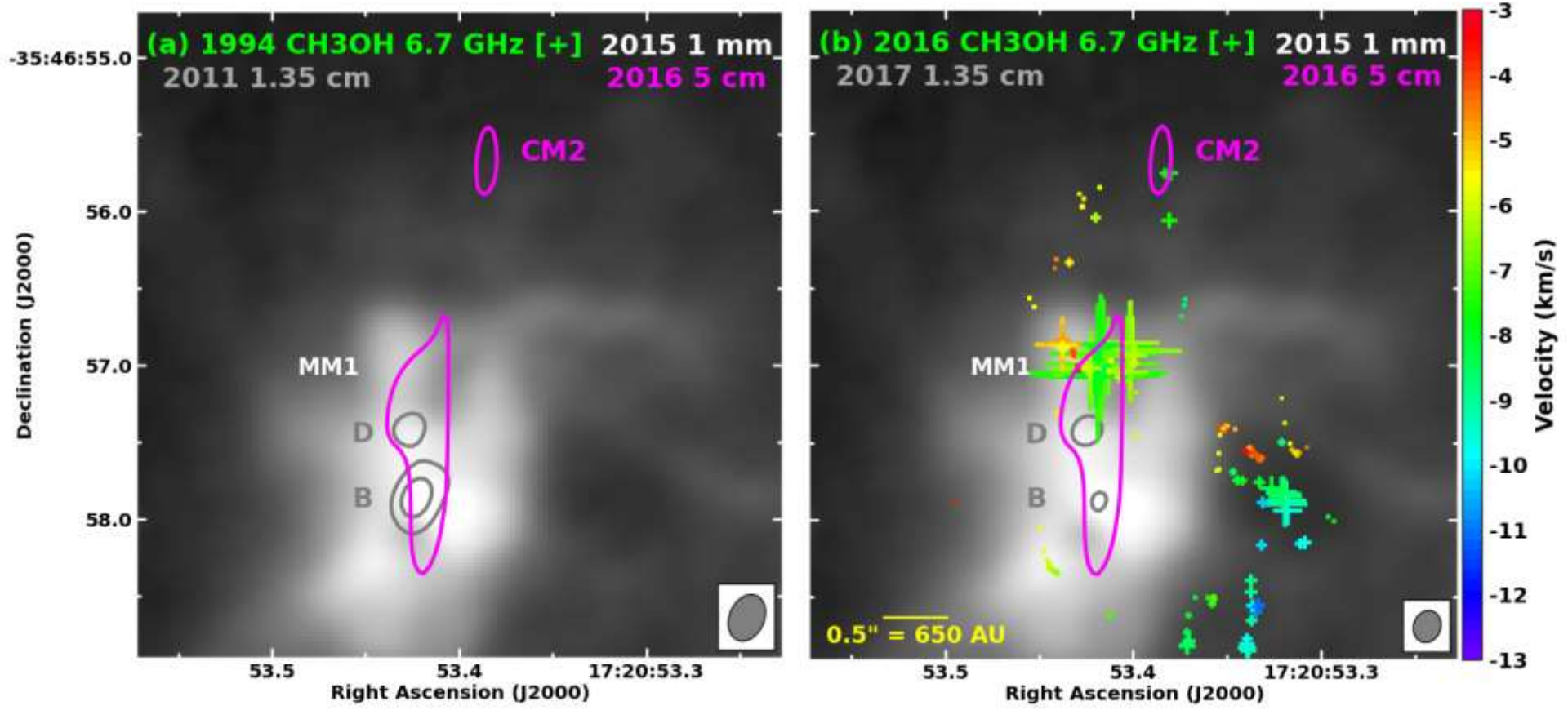
Temporary change of location on HR diagram



Haemmerle & Peters (2016)

How to distinguish?

- Long-term: measure lifetime of outburst
- Short-term: Confirm disk properties


(a) 1994 CH3OH 6.7 GHz [+]
2015 1 mm
2011 1.35 cm
2016 5 cm
CM2
MM1
D
B
(b) 2016 CH3OH 6.7 GHz [+]
2015 1 mm
2017 1.35 cm
2016 5 cm
CM2
MM1
D
B
0.5" = 650 AU
-35:46:55.0
56.0
57.0
58.0
Declination (J2000)
53.5
53.4
17:20:53.3
Right Ascension (J2000)
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
Velocity (km/s)