The University of Manchester

CONSTRAINING THE MASS AND EVOLUTION OF THE PROTOSTARS IN SDC335

ADAM AVISON

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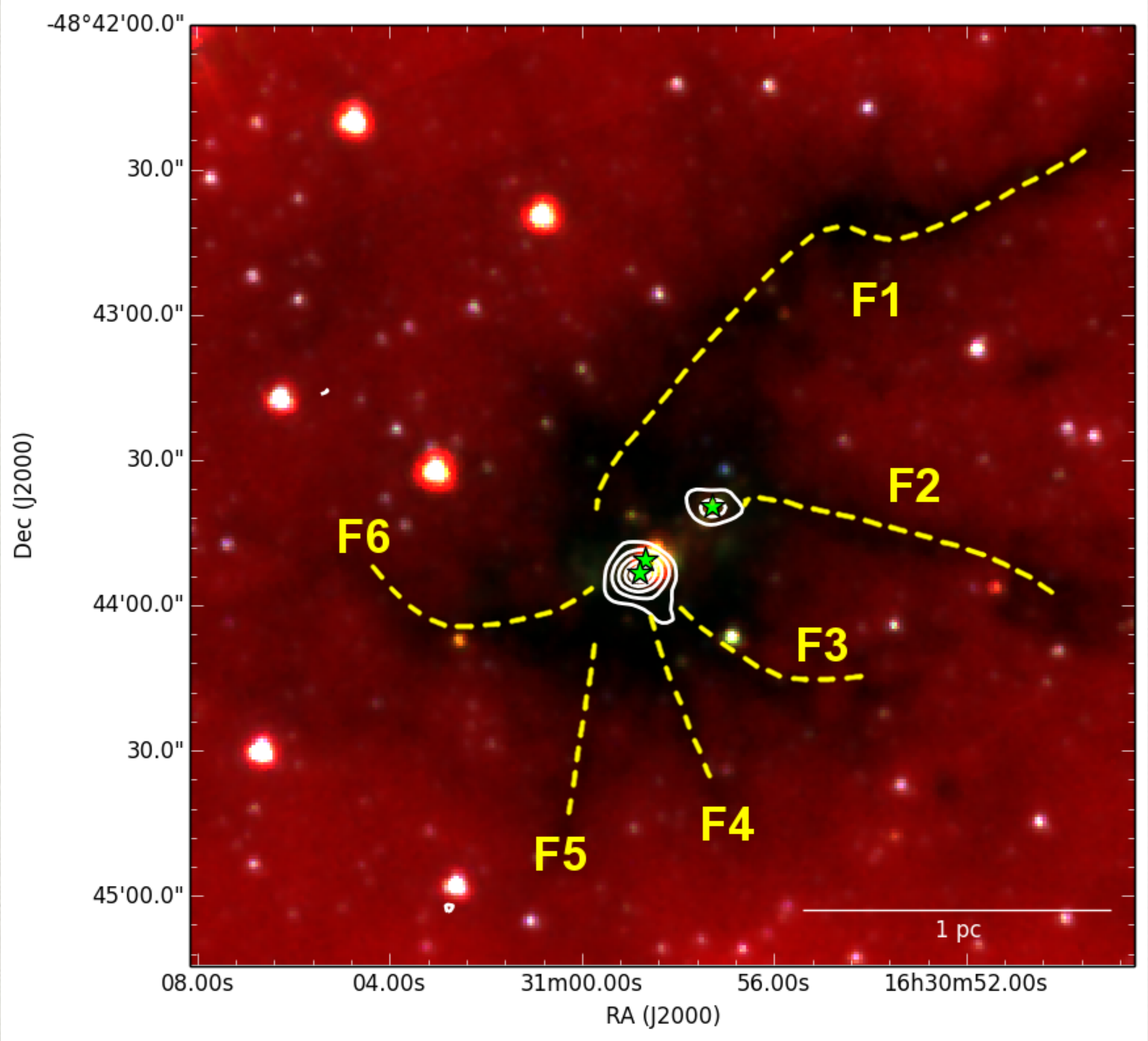
Overview

- Introducing SDC335
- Dense cores
- Compact HII regions
- mm-Core properties
- What does it all mean?

The IRDC SDC335.579-0.292

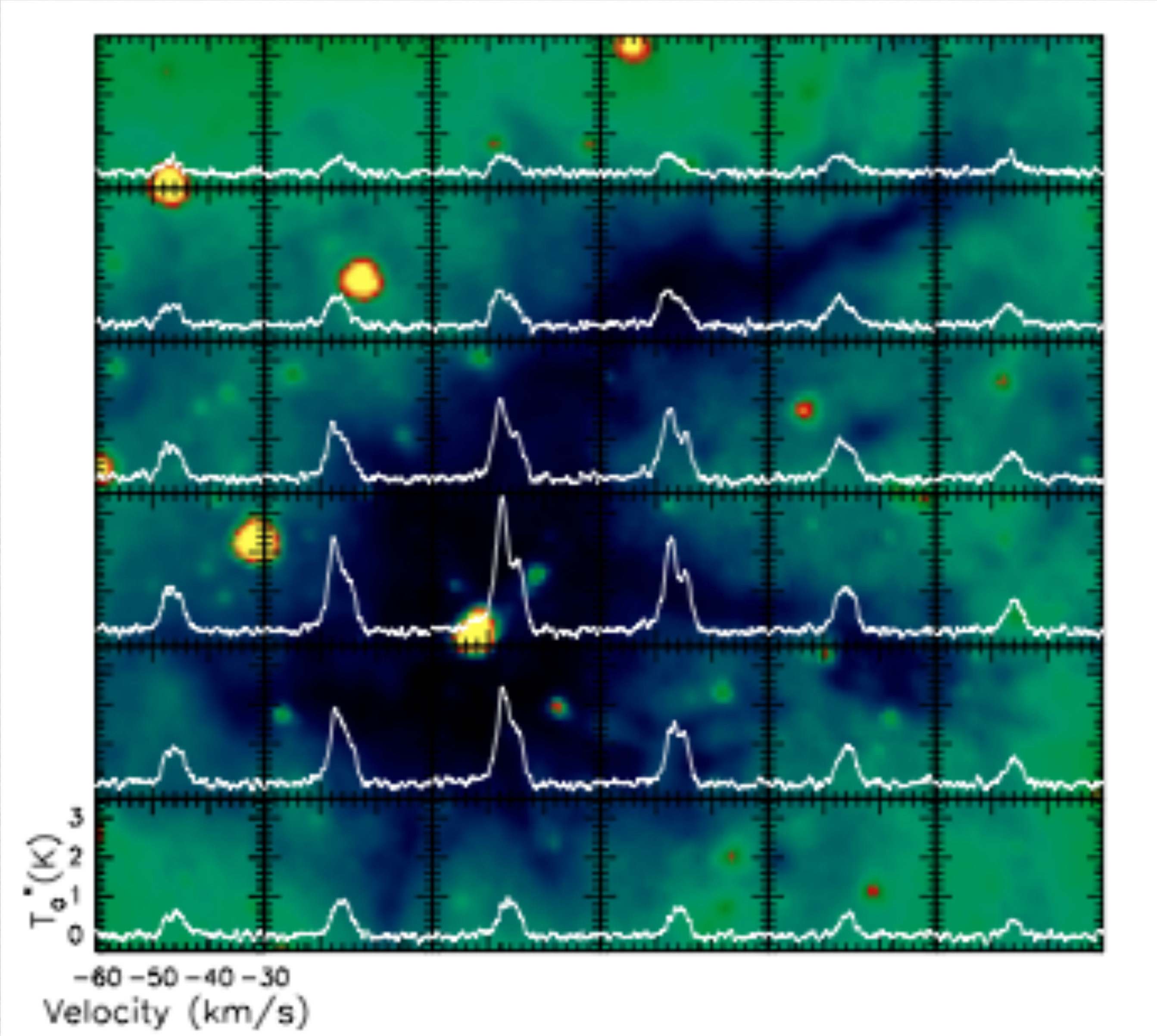
- Network of filaments
- Total mass ~ 5500 $M_\odot$
- Converging at two IR bright central objects (>2×10^4 $L_\odot$)
- No previous free-free emission detection at 6cm (Garay et al 2002.)



3-colour Spitzer IRAC image. Red 8µm, Blue 4.5µm Green 3.6µm
Contours ALMA 3.2mm continuum, green stars CH_3OH 6.7GHz masers

Collapse in SDC335

- Mopra HCO+:
  Self-absorbed blue-shifted emission.
- Globally collapsing
  $V_{inf} = 0.7 \pm 0.2 kms^{-1}$
- ALMA Cycle 0 Data, N_2H+:
  filamentary collapse,
  $V_{inf} \sim 1.0 kms^{-1}$
- Assuming Global + Filamentary collapse in the vicinity of the core $M \approx 2.5x10^{-3}$ $M_{\odot}$/yr enough to collect 750 $M_{\odot}$ in a cloud free fall time. **(Peretto et al. 2013)**



Caption MOPRA
Velocity map, -47.5km/s blue/black -45.5km/s pink/white.
Both images from **Peretto et al. 2013**

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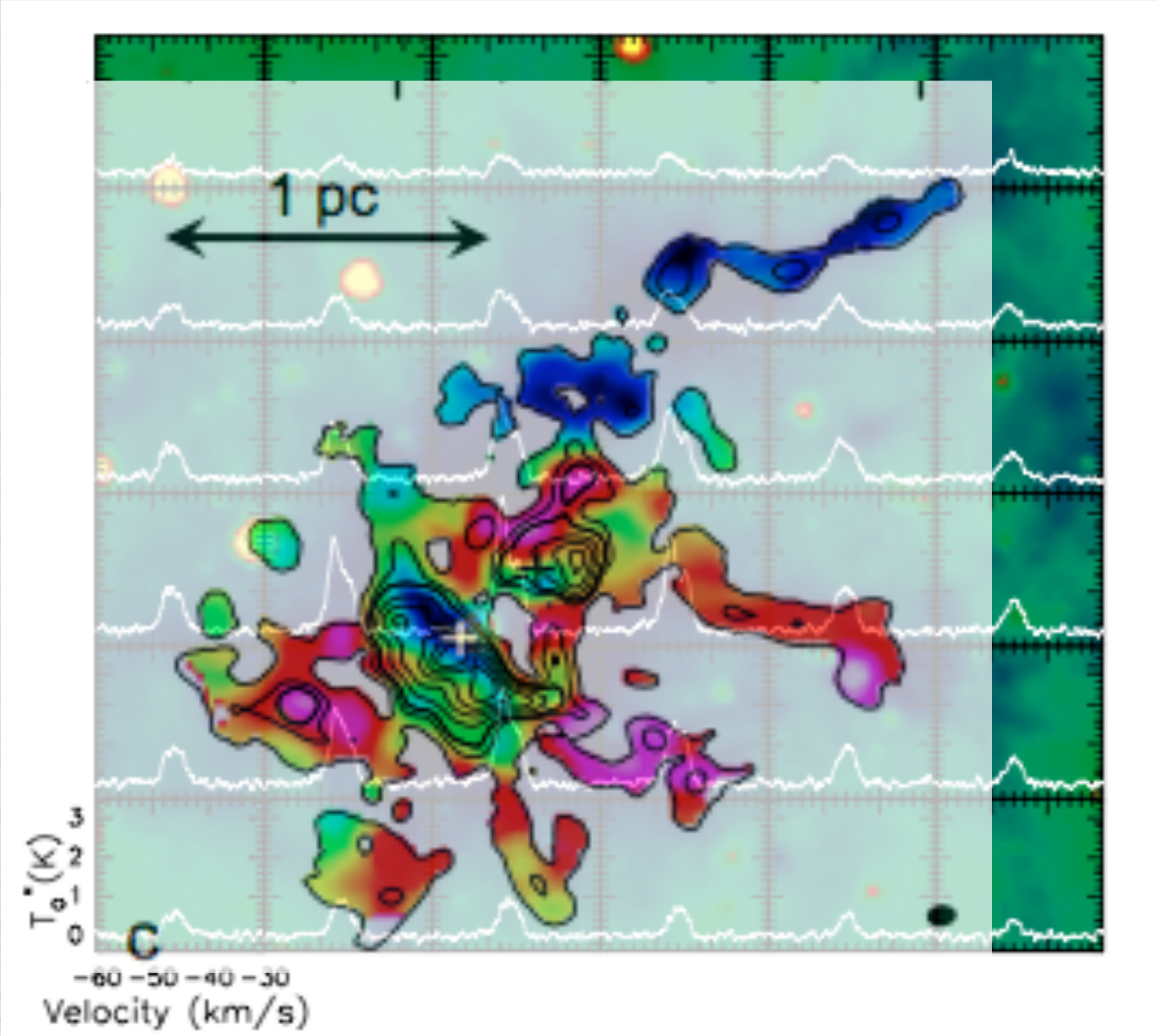

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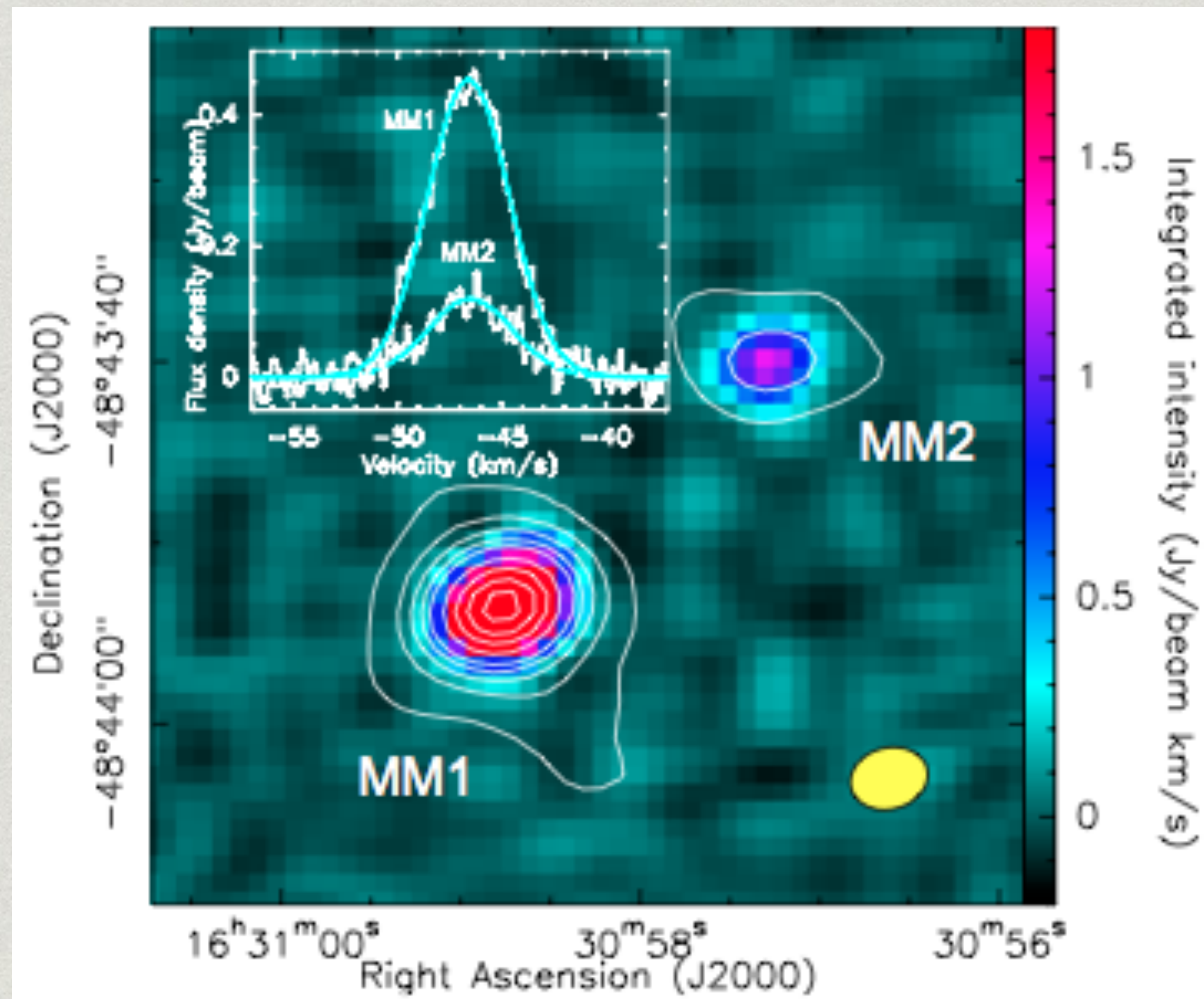
The central dense cores

- Calculated core masses from ALMA 3.2mm* **(Peretto et al 2013.)**
  MM1: M_{H_2} ~500 $M_\odot$
  MM2: M_{H_2} ~50 $M_\odot$

- Signs of MSF:
  - At least one Class II CH_3OH maser per core **(Caswell et al. 2011)**
  - EGO present in central region **(Cyganowski et al. 2008)**



CH3OH (13-12) integrated intensity **(Peretto et al. 2013)**
HNC outflows, ALMA. **(Pineda et al. in prep)**

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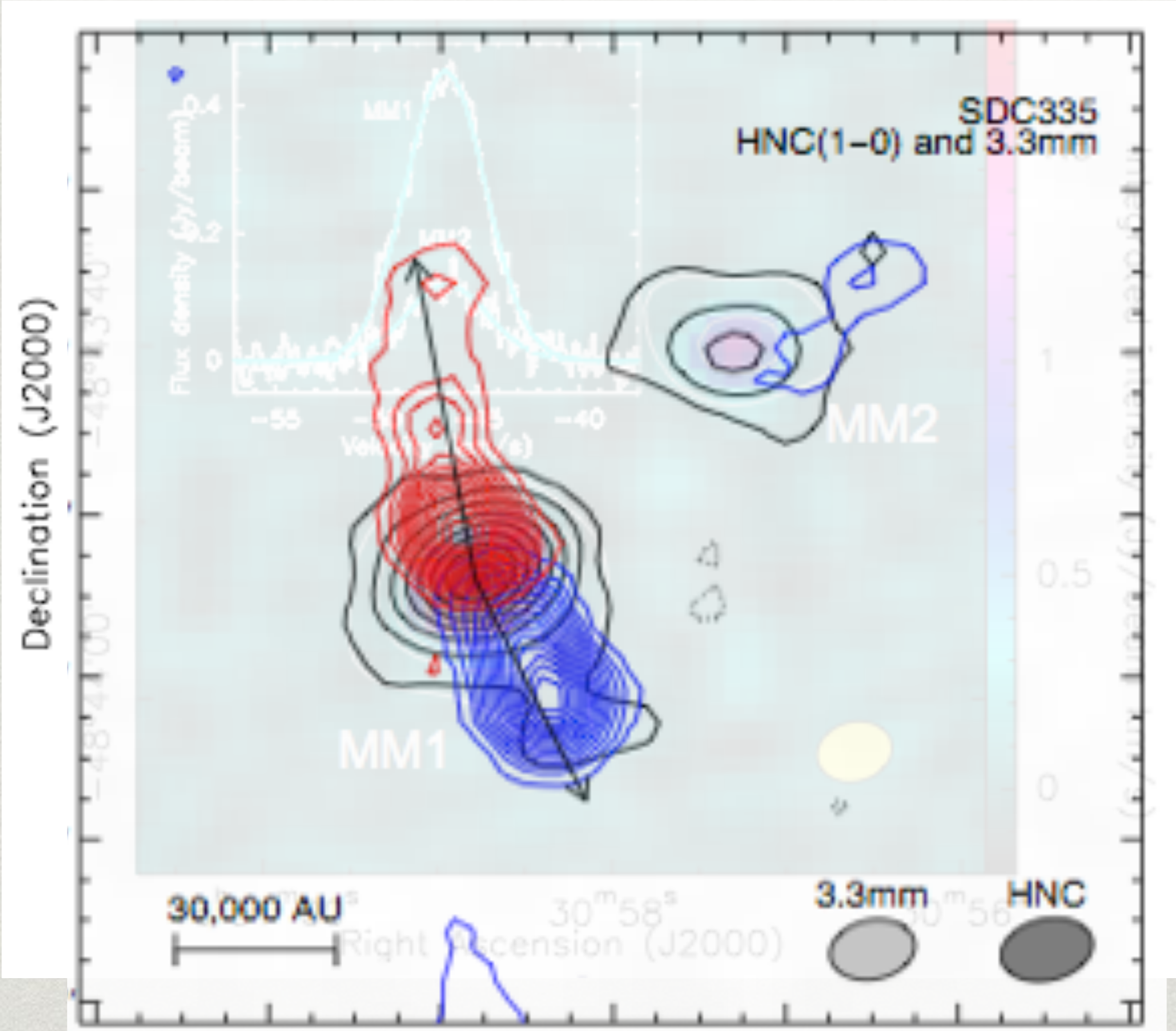

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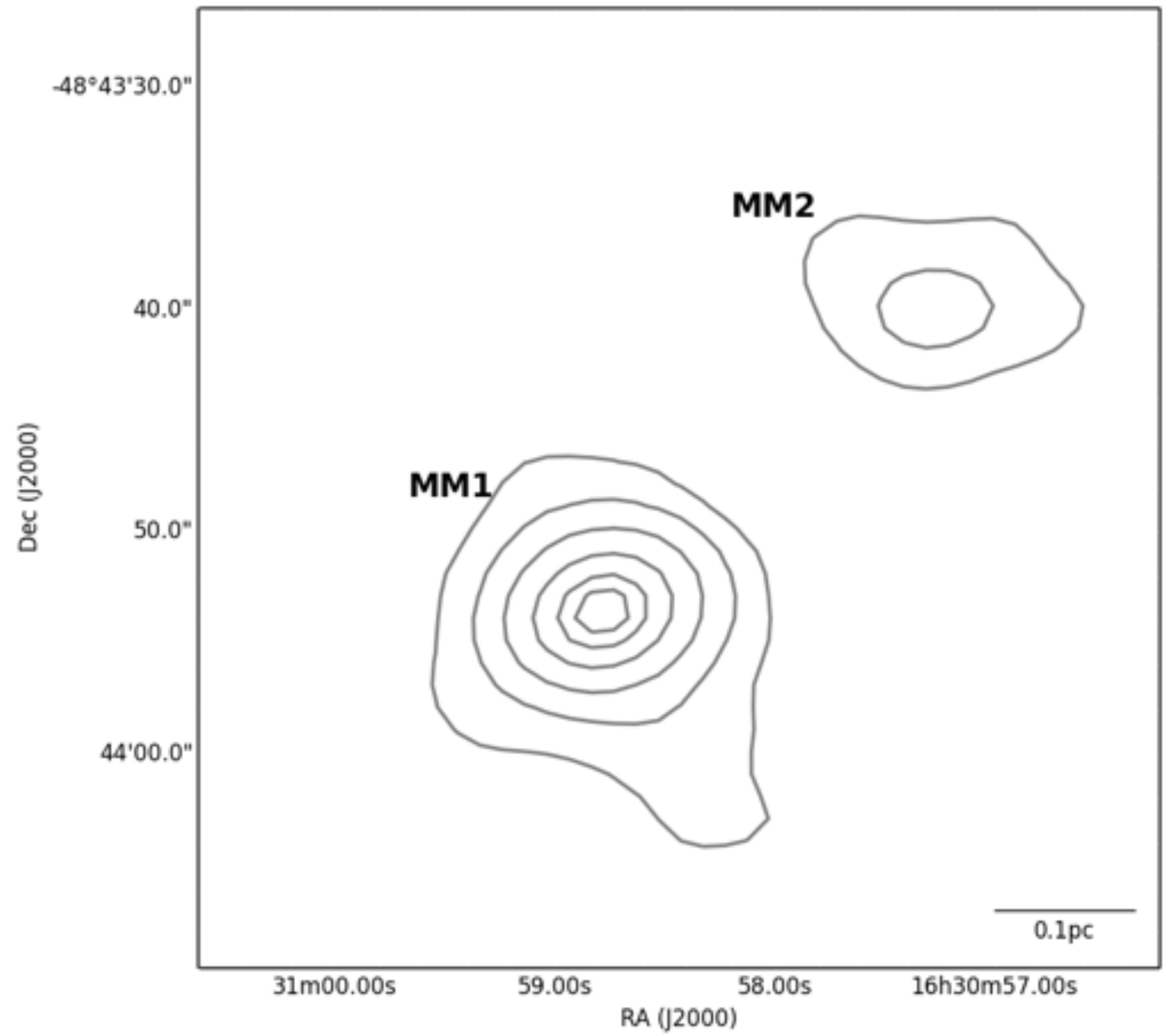


Instrument	*Freq.* [GHz]	*ΔS* [mJy/bm]	Beam [″×″]
ALMA	93.7	0.400	5.6×4.0
ATCA	25.0	0.023	1.9×1.0
ATCA	23.0	0.026	2.1×1.1
ATCA	8.0	0.008	2.3×1.0
ATCA	6.0	0.013	2.9×1.4

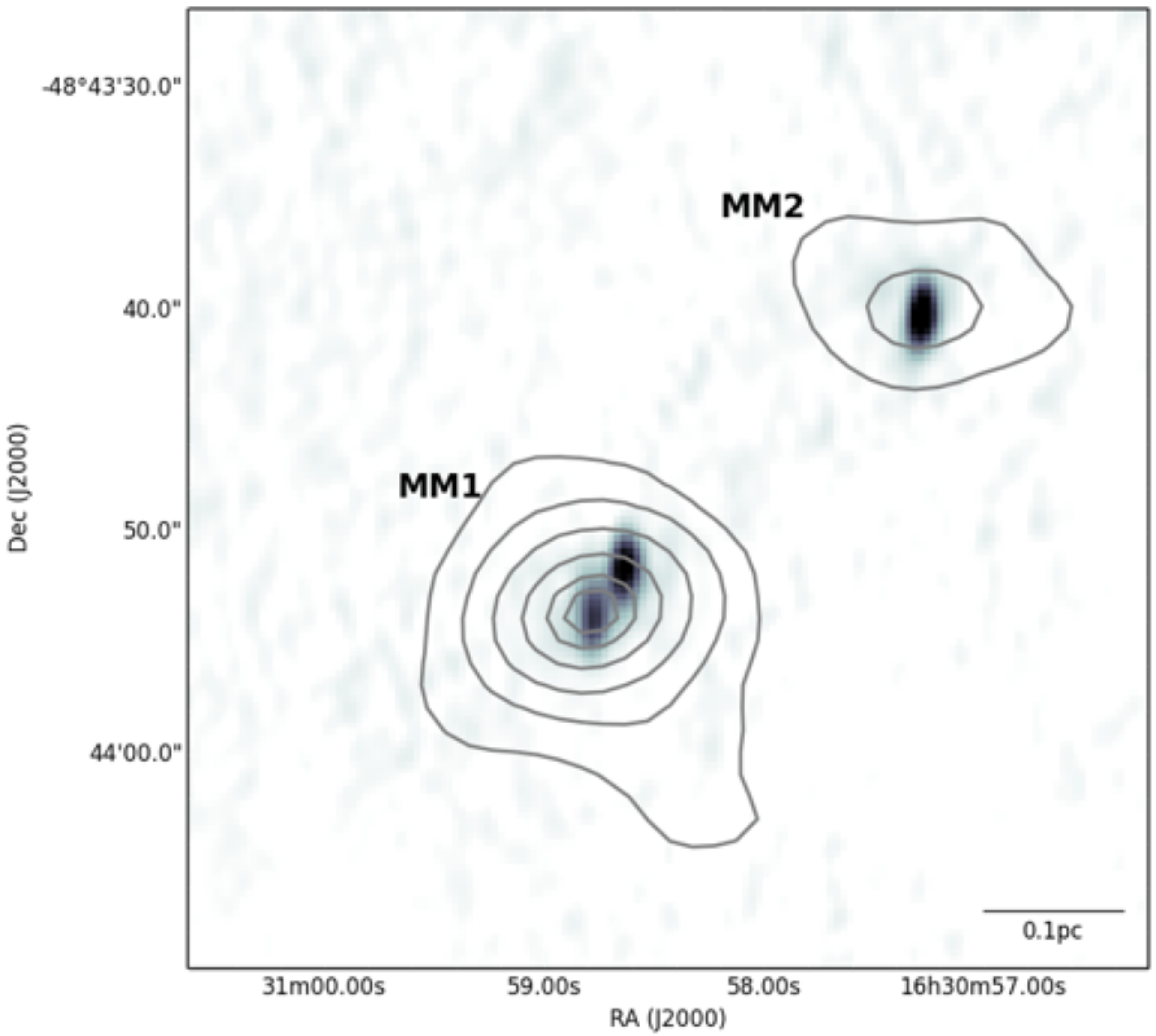
ALMA 3.2mm cont.

(Grey contour)

RADIO VIEW OF SDC335

FOLLOWING UP WITH ATCA.

Avison et al. 2015 (A&A, in press or arxiv.org/abs/1501.04638)



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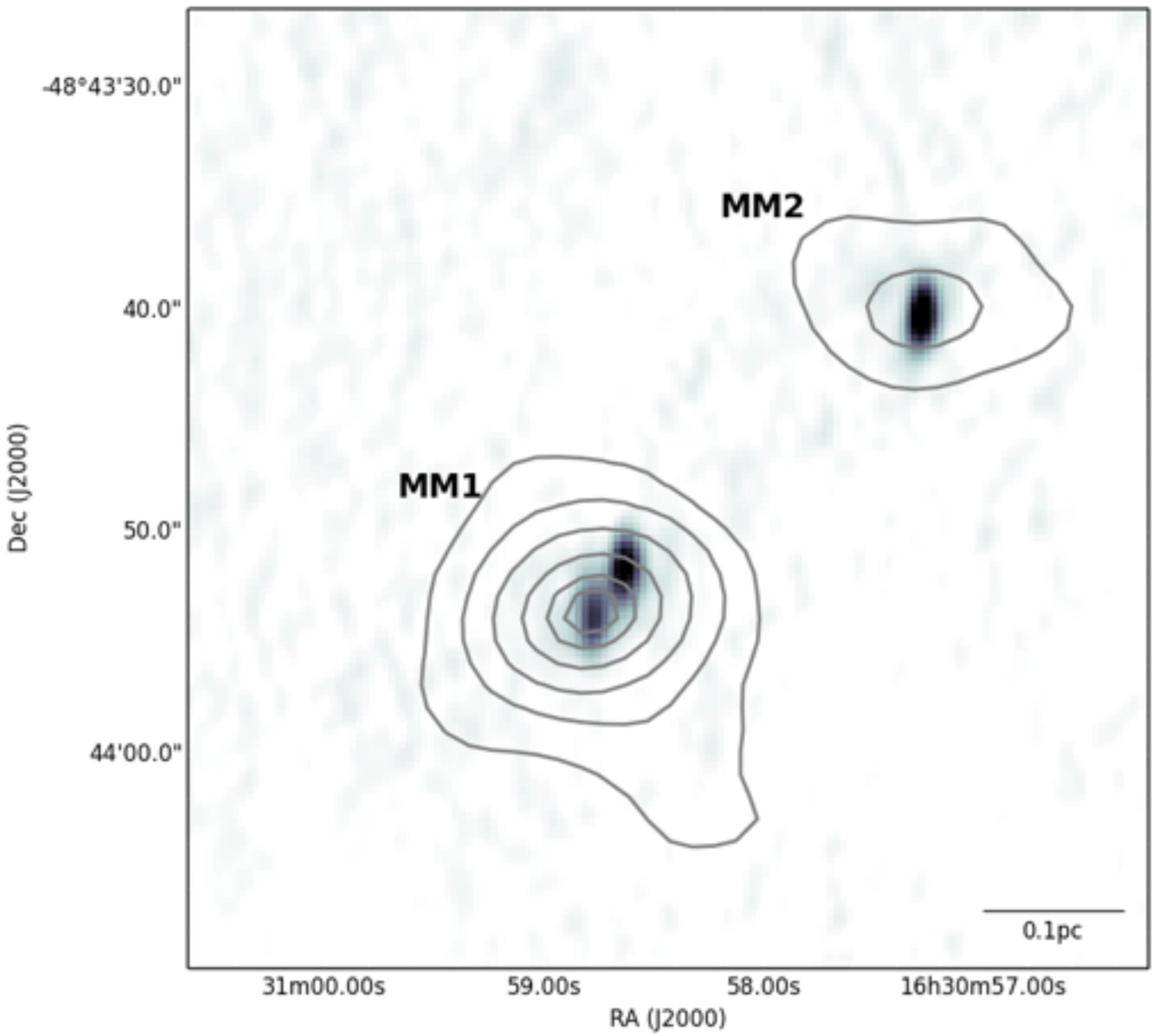

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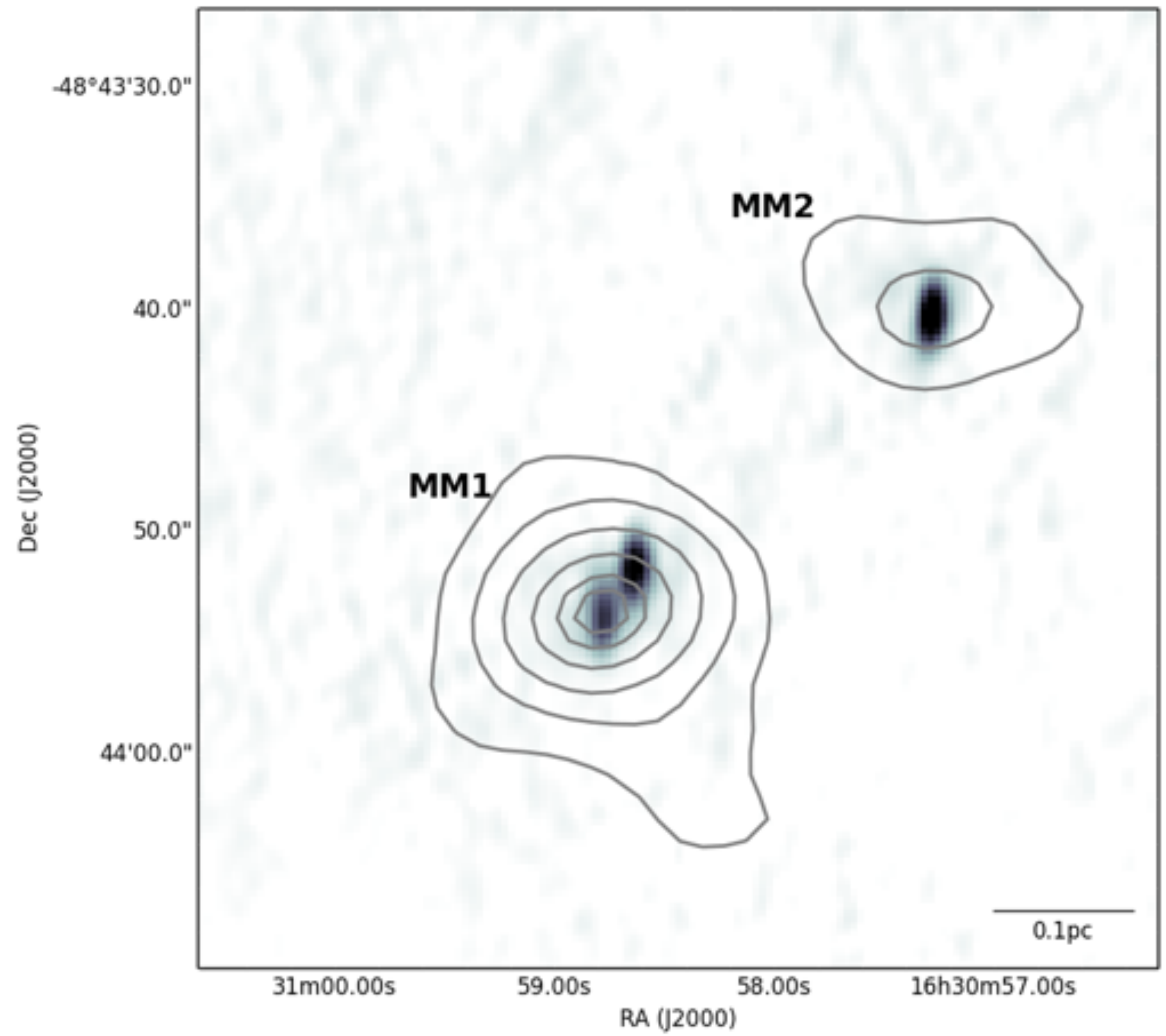

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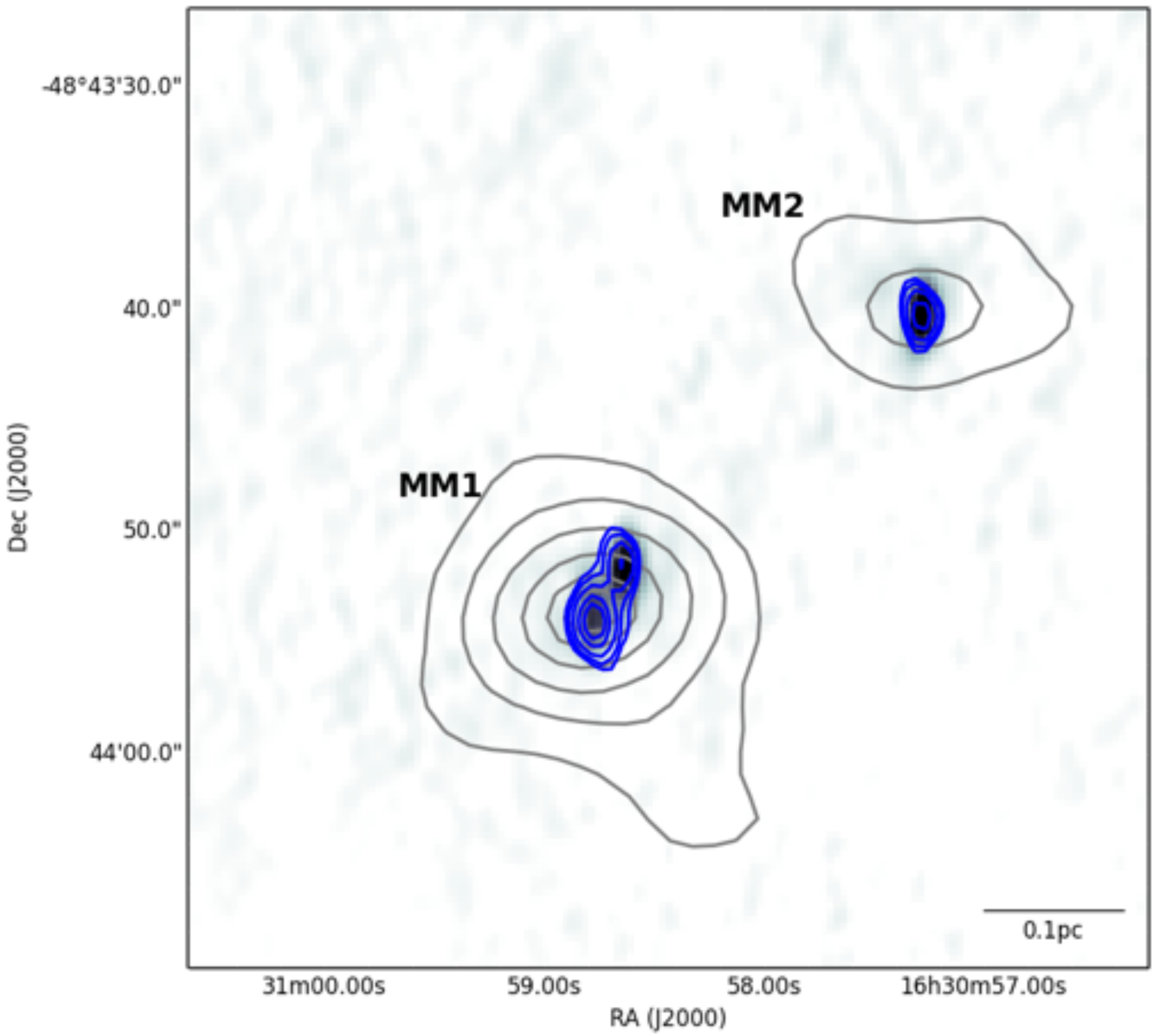

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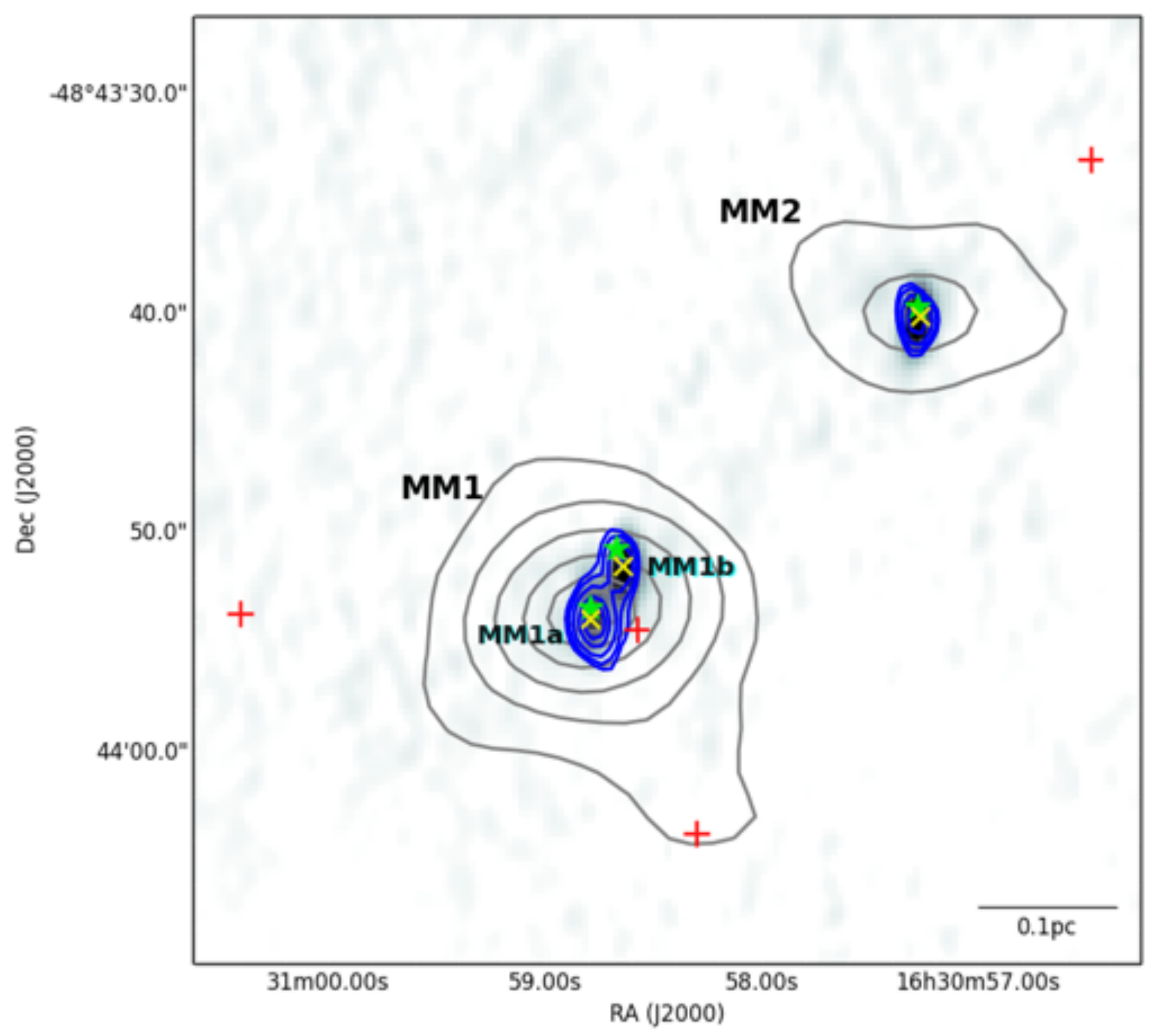

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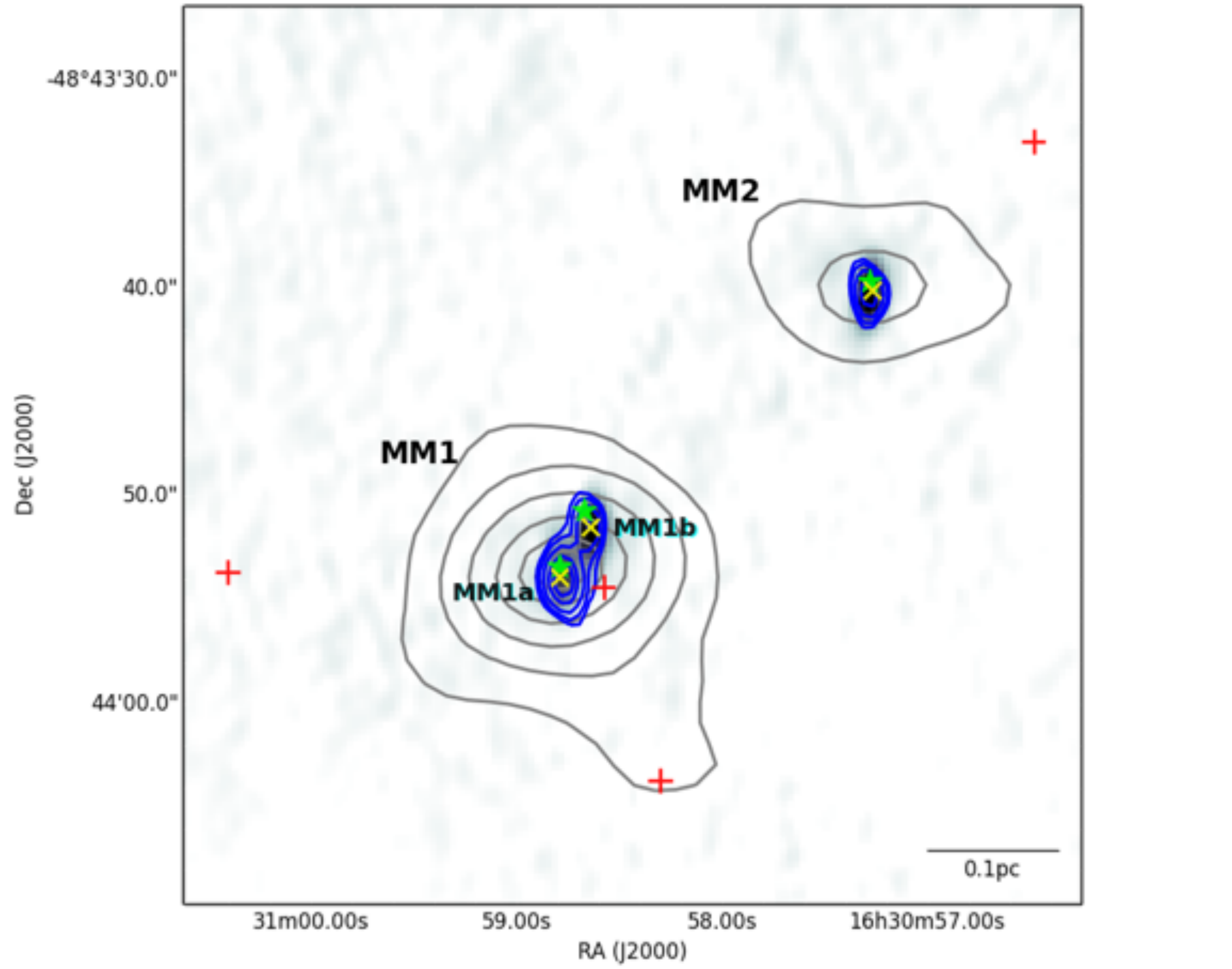

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6.7GHz CH_3OH masers
(MMB papers)

22GHz H_2O masers
(Breen 2010 & this work)

44GHz CH_3OH masers
(Avison, Cunningham & Fuller in prep)

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ATCA 8GHz cont. (Greyscale)

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RADIO VIEW OF SDC335

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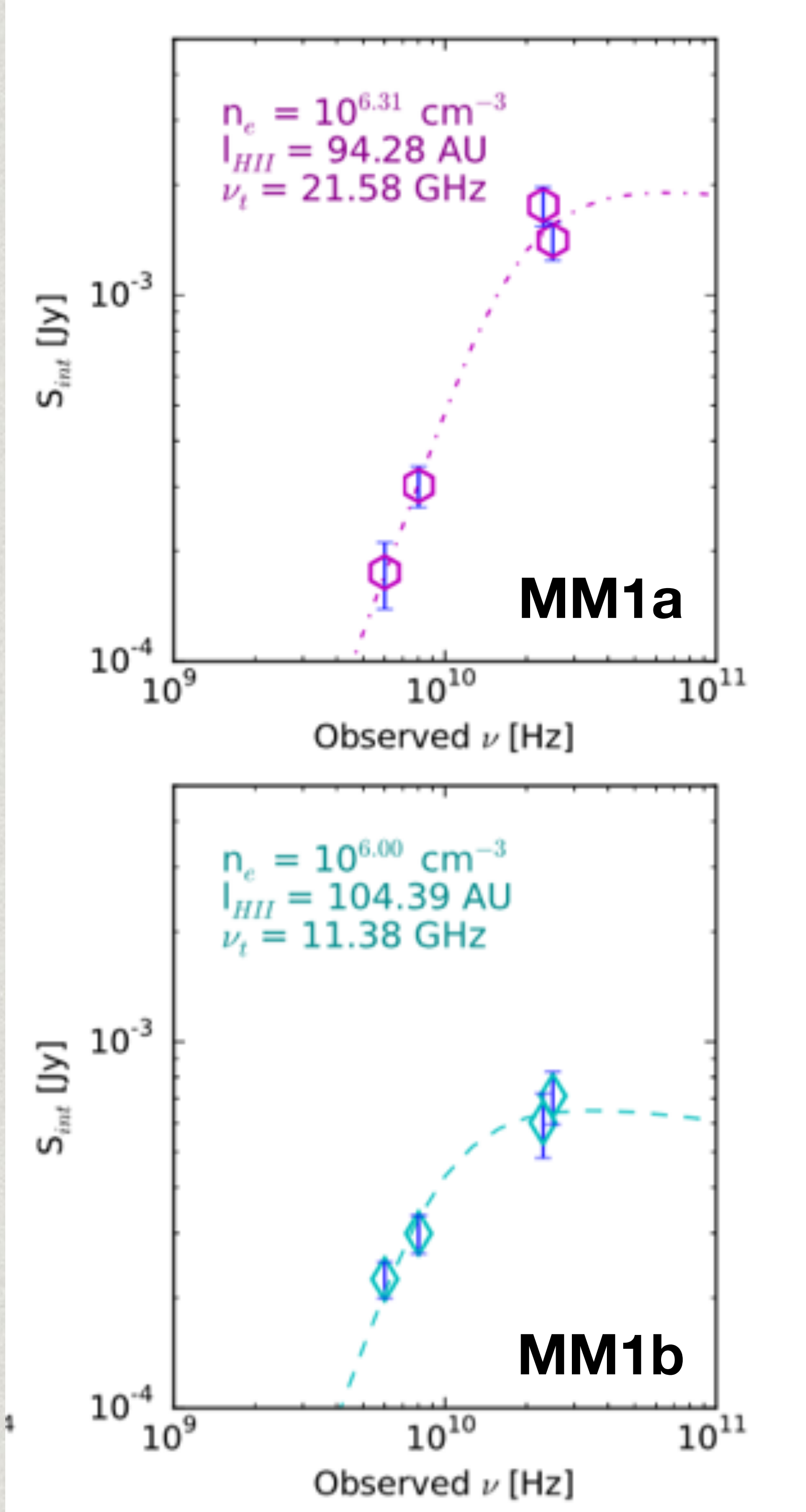
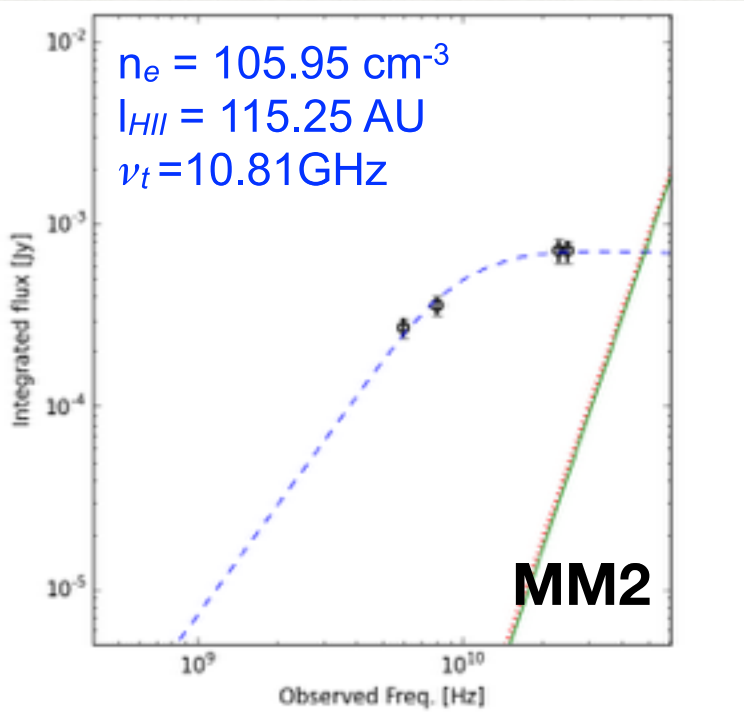
Compact HII regions in SDC335



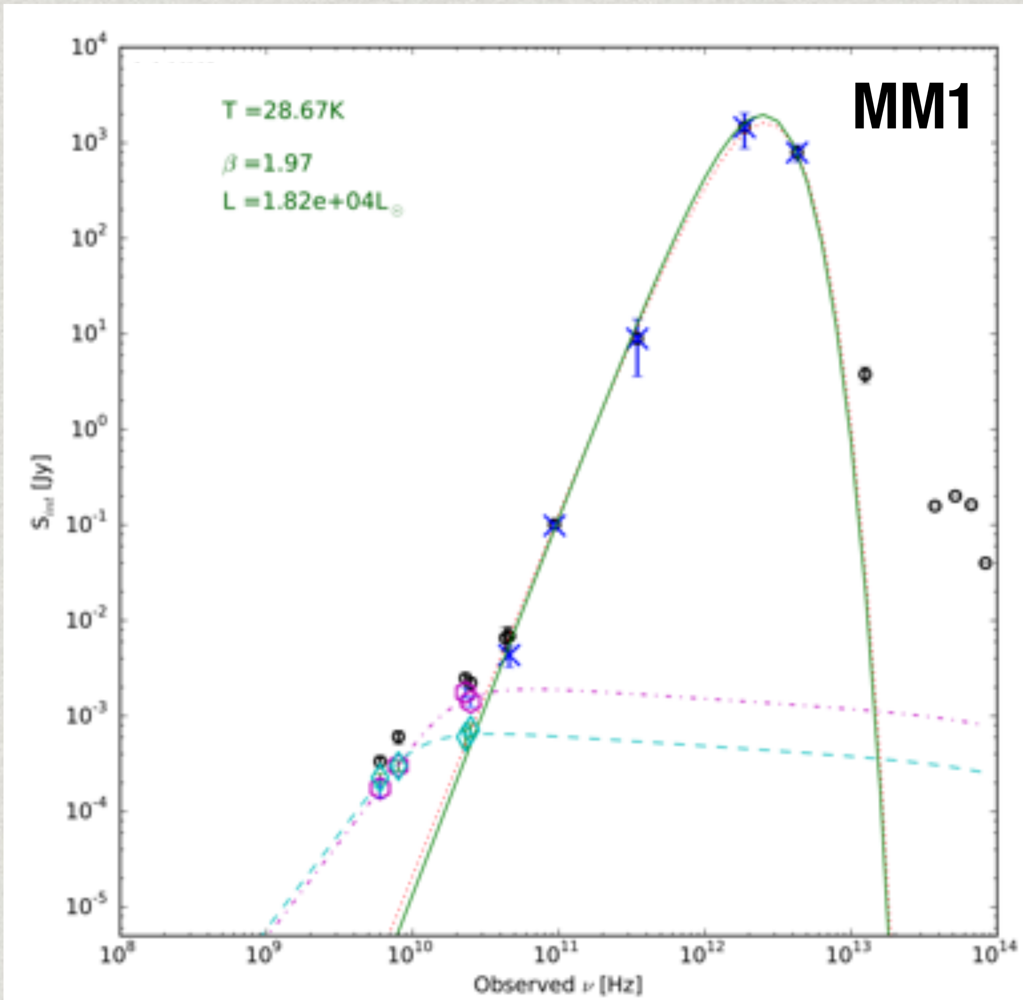


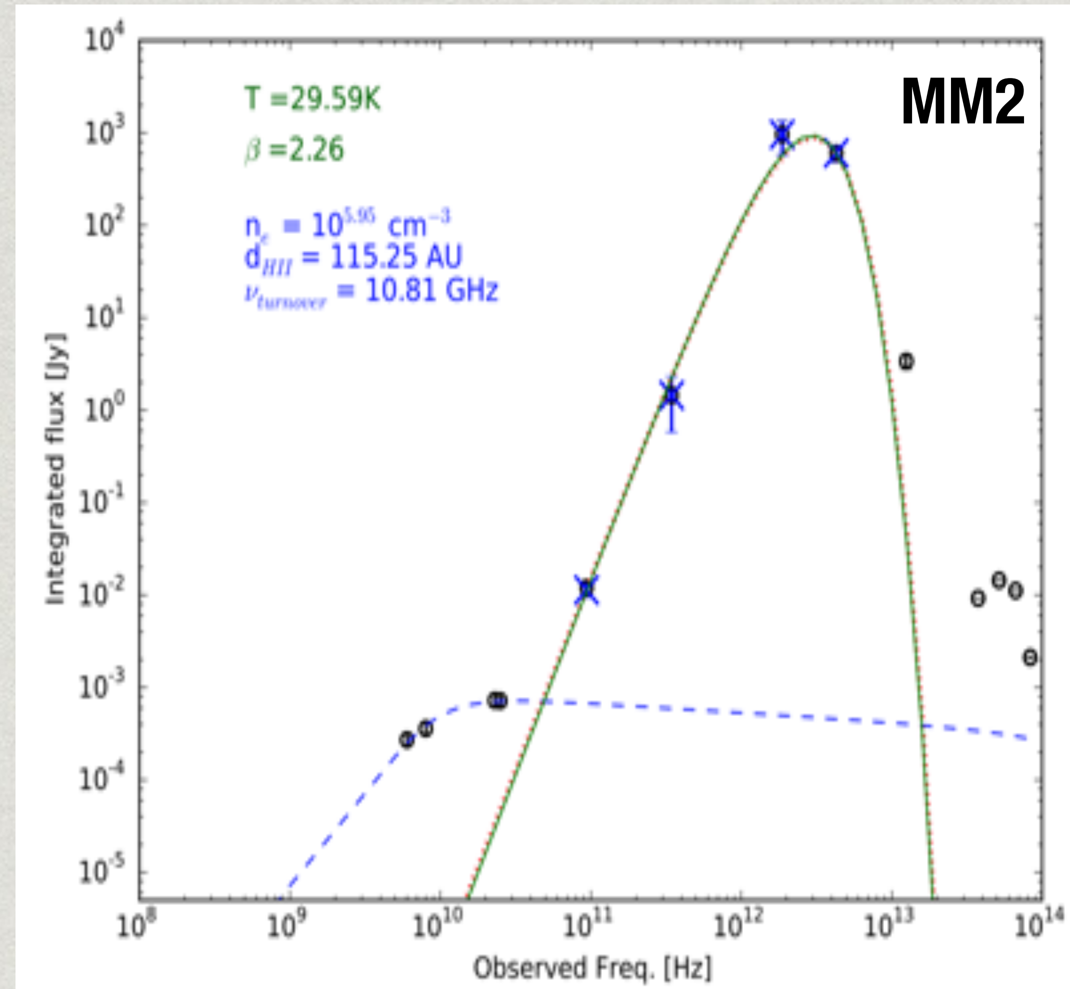
Three compact HII with characteristics in the HCHII regime **(e.g. Kurtz 2005)**

OBJECT	*EM* [pc cm^{-6}]	N_{lym} [γs^{-1}]	ZAMS*
MM1*a*	$10^{9.28}$	>$10^{45.3}$	>B1-B1.5
MM1*b*	$10^{8.70}$	$10^{44.8}$	B1.5
MM2	$10^{8.65}$	$10^{44.9}$	B1.5

*ZAMS based on **Davies et al. 2011** and **Mottram et al. 2011**

mm-Core SED fitting





OBJECT	T[K]	β	L_C [$L_\odot$]	M_C [$M_\odot$]
MM1	28.7(±2.3)	1.97(±0.15)	1.8×10^4	$763(^{+165}_{-171})$
MM2	29.6(±7.2)	2.26(±0.52)	9.9×10^3	$173(^{+65}_{-66})$

“That’s all well and good, but what does it tell us?”

Evolutionary status of the ionizing sources

- Sources still accreting… accretion drives outflows, (we have HNC outflow, EGO & central H_2O masers)
- Luminosity in accretion phase:

$$L_{tot} = L_* + L_{acc}$$

$$L_{acc} = \frac{GM_* \dot{M}_*}{R_*}$$

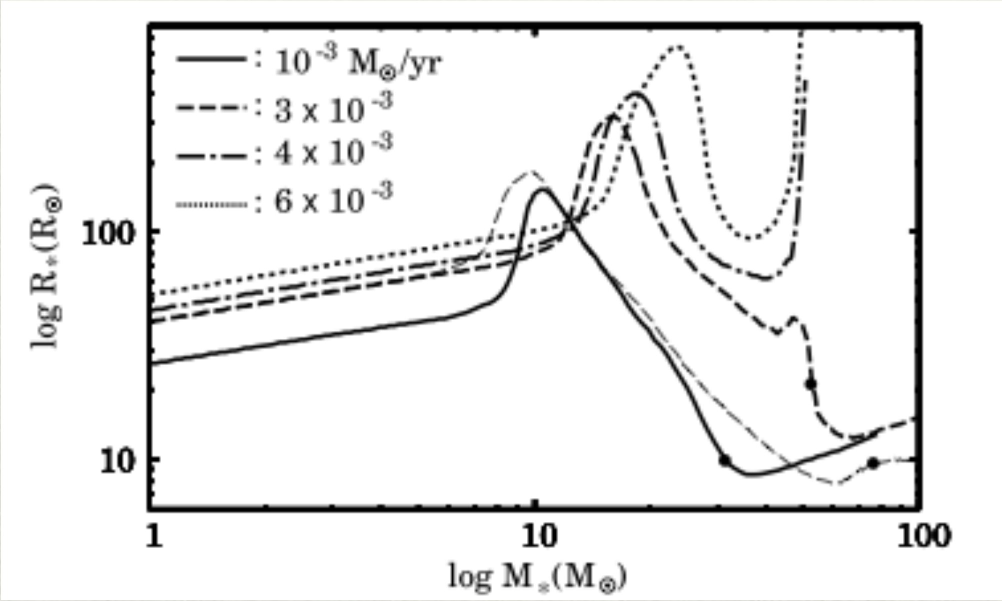
- Our SED fitted L_c << than expected L_{tot} (by ×16 for MM2) from ZAMS values.
- Telling us something about the formation of these objects…

Source	$L_{\star(ZAMS)}$ [$L_\odot$]	L_{acc} [$L_\odot$]	L_{tot} [$L_\odot$]
MM1*a*	5.48×10^3	2.22×10^5	2.27×10^5
MM1*b*	4.10×10^3	2.16×10^5	2.20×10^5
MM2	4.35×10^3	2.17×10^5	2.21×10^5

Solutions to our luminosity problem?

Swollen Cores:

- The after effects of protostellar surface swelling *a la* **Hosokawa & Omukai 2009 (image below), Hosokawa, Yorke & Omukai 2010**



- Indicates our ZAMS masses are a lower limit

Lower/Decreasing/Periodic Accretion:

Alternatively, our assumed accretion rate (2.5 ×10^3 Myr^{-1}) could be too high.

A factor 20 reduction still leaves us with a reasonable accretion rate for MSF. **(e.g.Fuller et al. 2005; Churchwell et al. 2010; Klaassen et al. 2012; Rygl et al. 2013; Duarte-Cabral et al. 2013)**

Decreasing or periodic accretion rates could also account for the discrepancy.

However, **Davies et al. 2011** found that decreasing (or indeed constant) accretion rates don't fit the observed massive star pop of the galaxy.

Periodic accretion currently has no general consensus as to whether its been observed on not!

The Future of SDC335

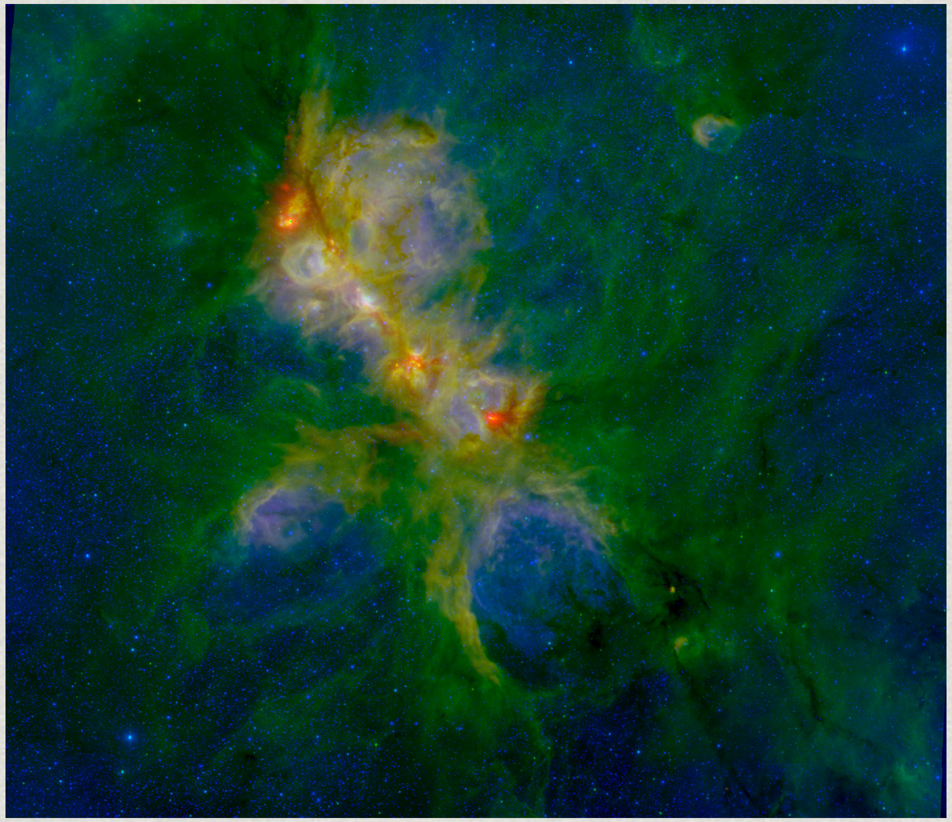
- Given we have $N_\star$ ($M_\star$>~10 $M_\odot$) = 3
- Use power law form of the IMF in mass range 1-120 $M_\odot$, assume α=2.3-2.35 **(Kroupa 2002, Salpeter 1955)**.
- SDC335 has potential to form 60-66 stars in mass range 1-120$M_\odot$.
- Extending **Kroupa** IMF down to 0.08$M_\odot$ SDC335 could form ~1000 stars with 96% in sub-solar mass regime.
- SDC335 population total stellar mass = 285$M_\odot$
- Only 5% of the total current mass of SDC335,
- Lower than expected from typical SF efficiencies (10-30% **Lada & Lada 2003**).

The Future of SDC335:

Handy-wavy

- Three massive protostellar objects within 0.3pc of one another.
- Reminiscent of the Trapezium Cluster **(see e.g. Hillenbrand 1997; Muench et al. 2002)** and NGC6334 I(N) **(see e.g Hunter et al. 2014, Brogan et al. 2013)**.

Credit: NASA



Credit: S. Willis (CfA+ISU); ESA/Herschel; NASA/JPL-Caltech/ Spitzer; CTIO/NOAO/AURA/NS

The Future of SDC335:
with numbers

	Trapezium/ONC	NGC 6334 I(N)	SDC335
Inner Region	0.3pc (Trap)	0.21pc	0.3pc (MM1-MM2)
Total Region	3pc (ONC)	-	2.4pc
$N_\star(1<M_\star<150M_\odot)$	137	-	60
$N_\star$ ($M_\star$>10 $M_\odot$)	6	-	3
N(protostar)	-	~25	>3(?)
N(Radio Cont. Sources)	-	4	3

Column 2: Hillenbrand 1997.
Column 3: Hunter et al. 2014.
Column 4: Avison et al. accepted A&A

SUMMARY

- Radio continuum follow up of SDC335 reveals population of high mass protostellar objects in SDC335
- SED fitting to continuum allows ZAMS classification of HMPOs, constraining lower mass limits
- Multi-wavelength SED fitting provides bolometric luminosities for cool dust component
- Fitted luminosities suggestive of swollen cores or more complex accretion rates
- SDC335 could be forming a Trapezium like cluster

¡CHEERS!