Episodic accretion and outflows in the S255IR high mass star-forming region

Igor Zinchenko

Institute of Applied Physics,

Russian Academy of Sciences

S.-Y. Liu, Y.-N. Su, K.-S. Wang (ASIAA, Taiwan),

Y. Wang (MPIA)

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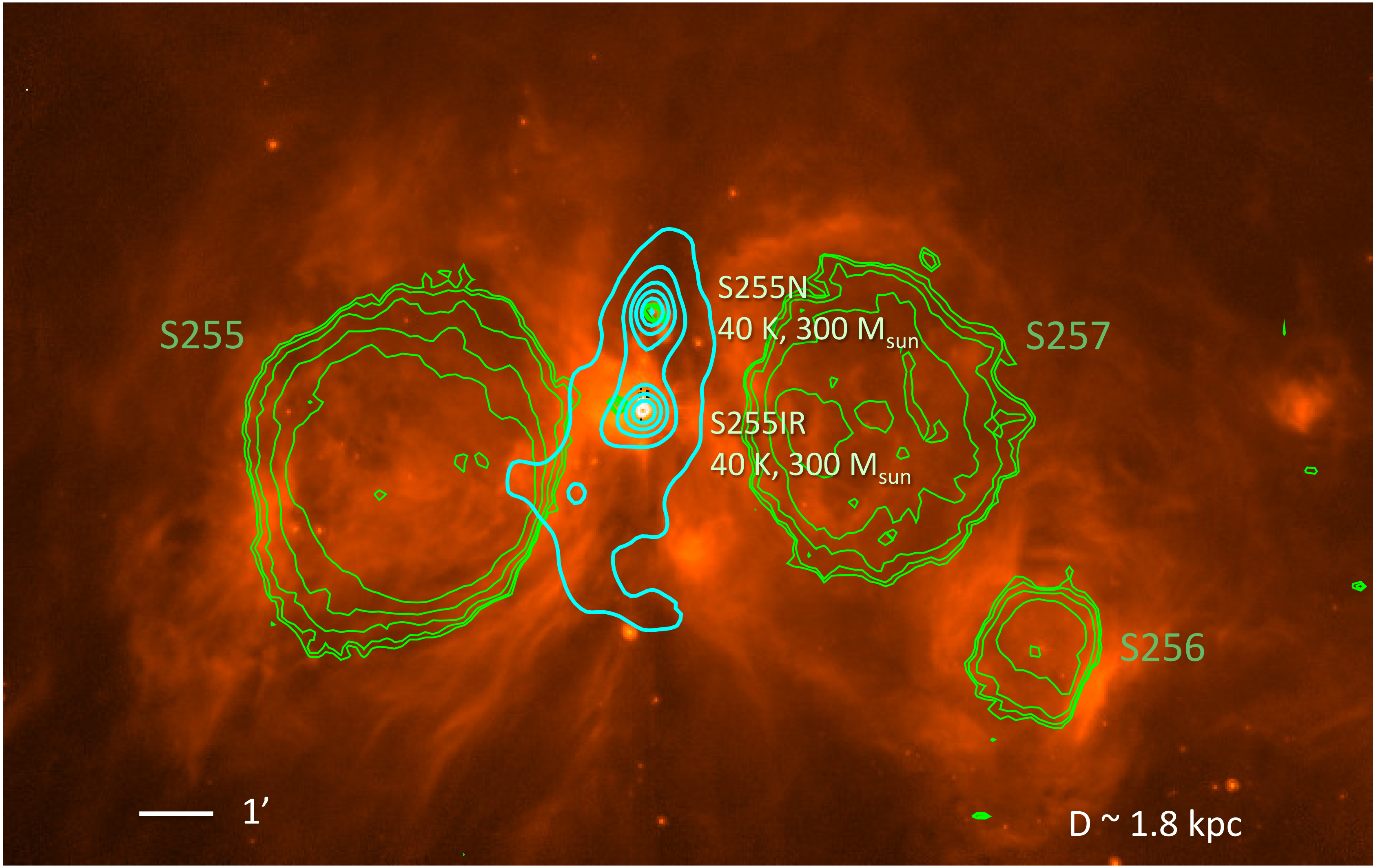
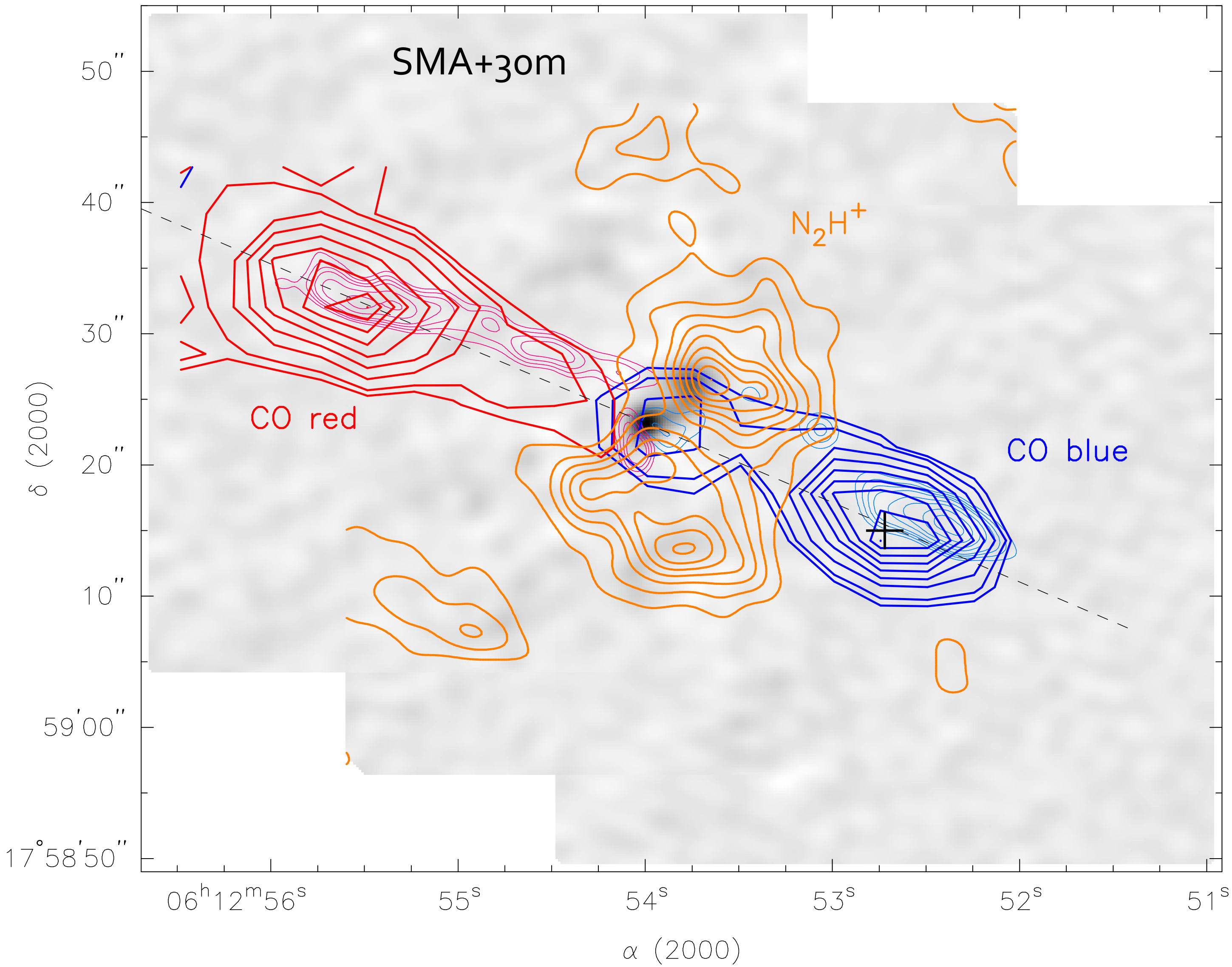
S255 star forming complex

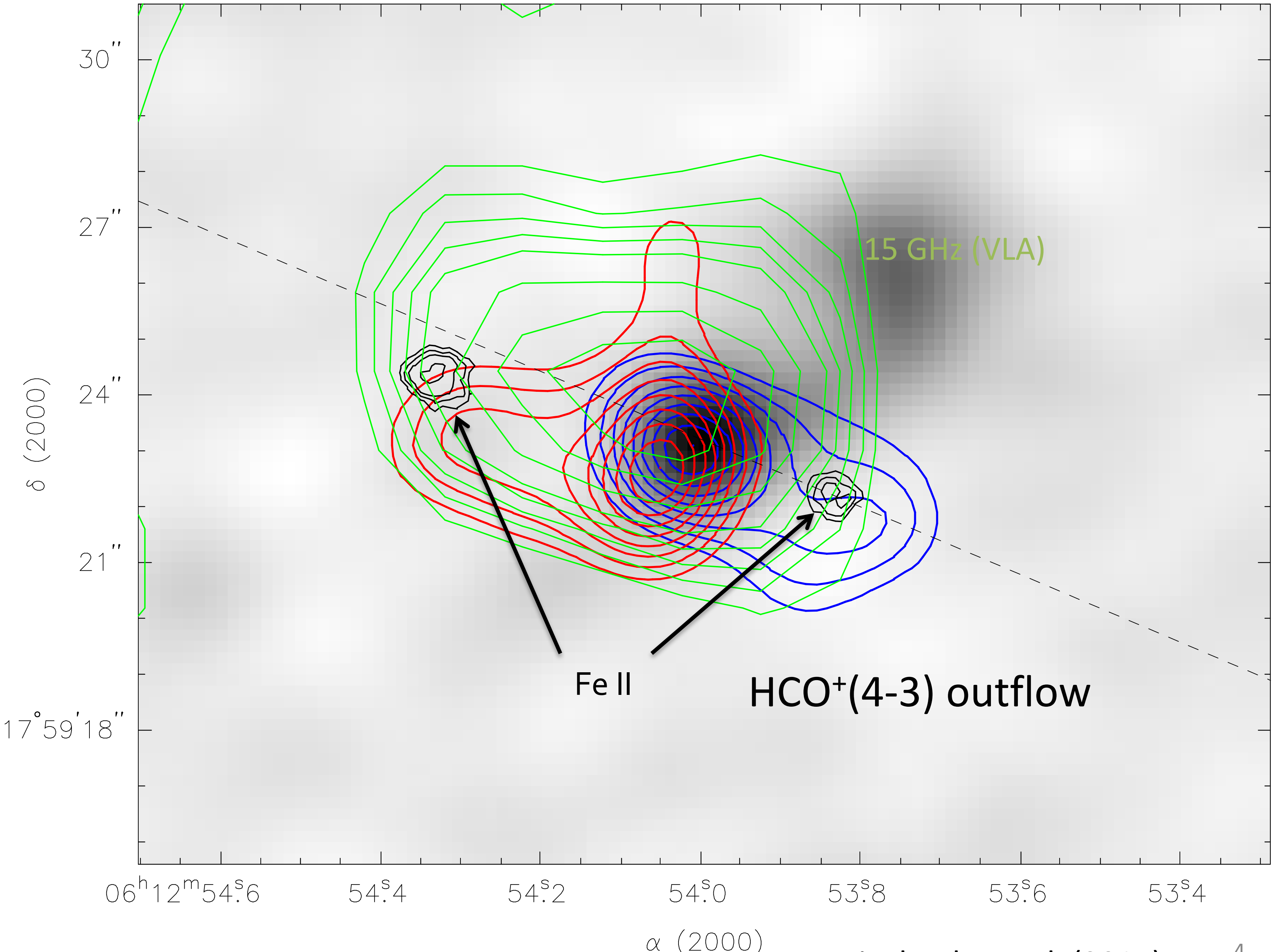


GMRT 610 MHz (green) and IRAM 30m 1.2 mm (cyan) contours overlaid on the Spitzer 8 μm image

High velocity outflow in S255IR



Zinchenko et al. (2015)



Zinchenko et al. (2015)

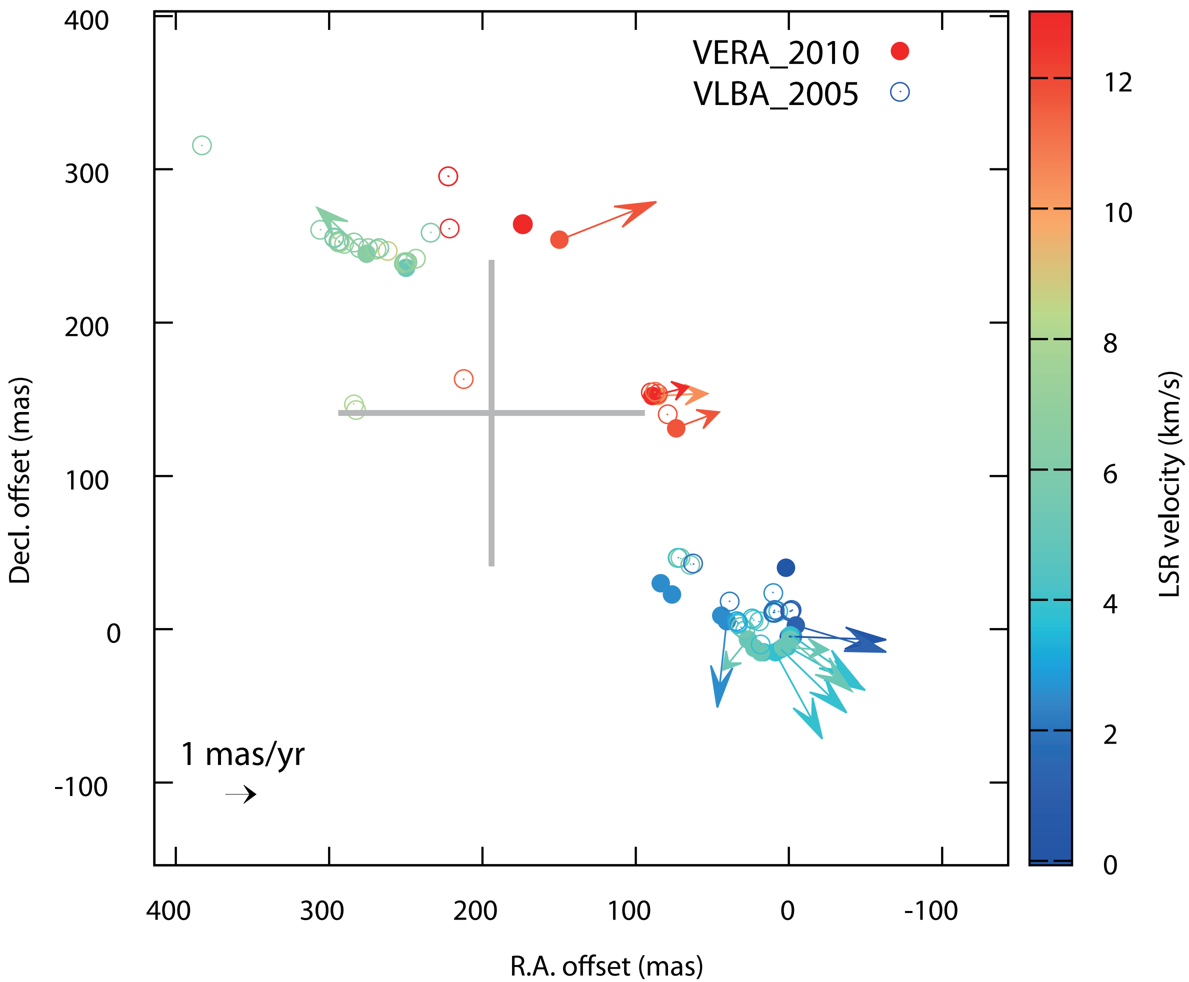


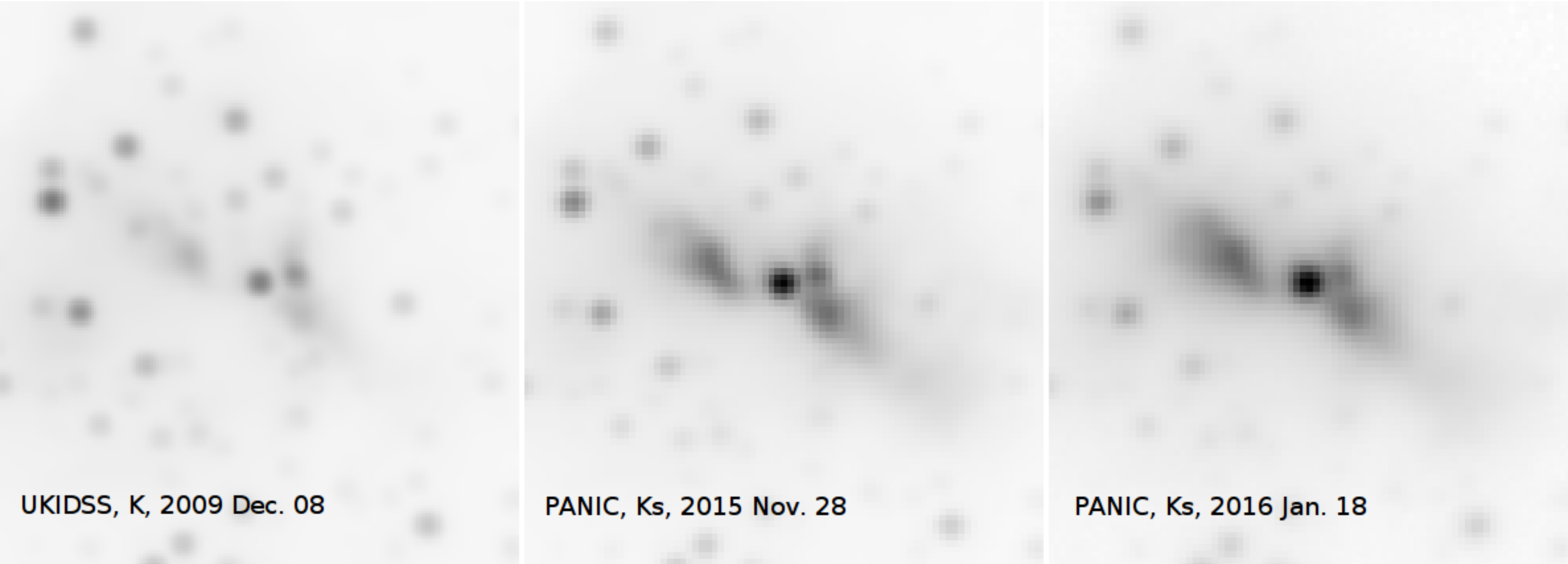
Figure 6. Distributions of water masers observed in 2005 using the VLBA (Goddi et al. 2007), and in 2010 using VERA (this work). Masers from the aforementioned works are shown as open and filled circles, respectively. The VLBA masers were shifted into the frame of the MYSO by correcting for the systemic motion over the 5 years elapsed between observations. The peak position of the centimeter source from Rengarajan & Ho (1996) is indicated with a cross whose size indicates to the positional error in the measurement.

Burns et al. 2016

Title: The methanol maser flare of S255IR and an outburst from the high-mass YSO S255IR-NIRS3 - more than a coincidence?

Bringfried Stecklum (TLS Tautenburg),), Alessio Caratti o Garatti (DIAS Dublin), Maria Concepcion Cardenas (IAA-CSIC Granada, MPIA Heidelberg), Jochen Greiner, Thomas Kruehler (MPE Garching), Sylvio Klose, Jochen Eisloeffel (TLS Tautenburg)
on ***25 Feb 2016; 11:25 UT***
Credential Certification: Bringfried Stecklum (stecklum@tls-tautenburg.de)

Further photometric monitoring and spectroscopy will show whether an FU Ori-type outburst from the HMYSO is ongoing which would be the first of its kind. The recent dimming in the K band seen in the latest PANIC image might indicate extinction changes due to disk scale height or accretion column variations.

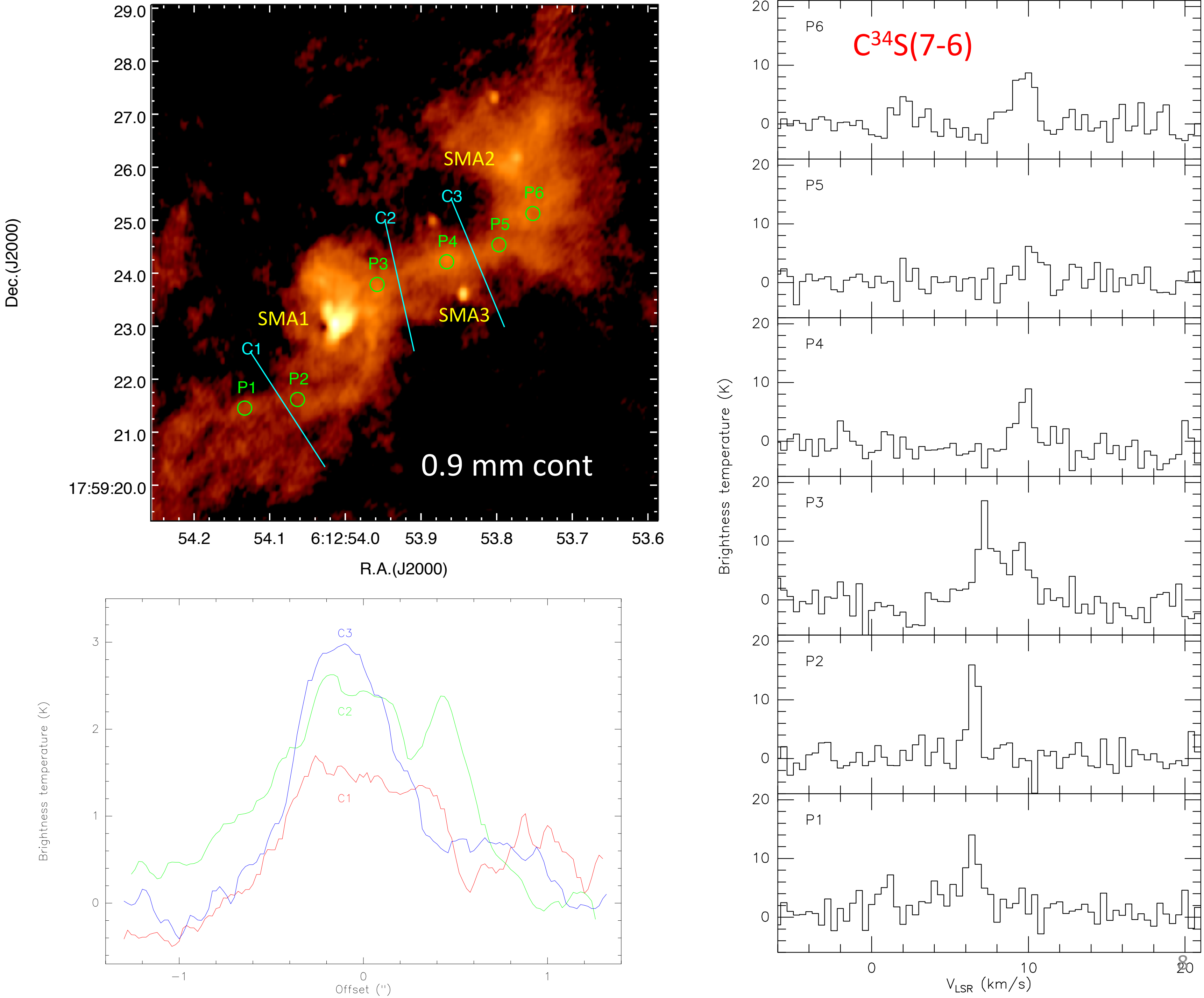


ALMA observations

In Band 7 at three epochs:
(1) on 2016 April 21 (projected baselines between 12 and 562 m),
(2) on 2016 September 9 (projected baselines between 12 and 2811 m).
(3) on 2017 July 20 (projected baselines between 15 and 3041 m).

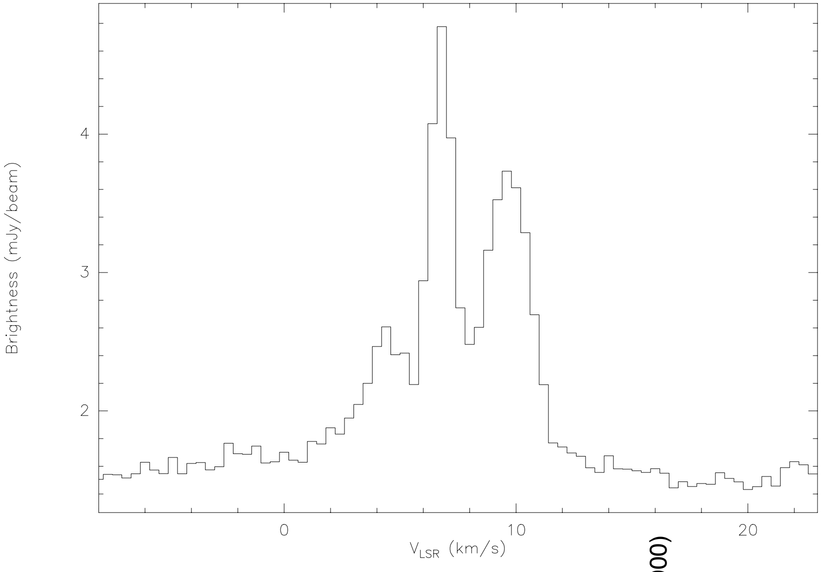
Four spectral windows centered at around 335.4 GHz, 337.3 GHz, 349.0 GHz, and 346.6 GHz, with bandwidths of 1875.0 MHz, 234.4 MHz, 937.5 MHz, and 1875.0 MHz, respectively.

Angular resolution 0.10” x 0.14” (Briggs weighting with a robust parameter of 0.5) ~ 200 AU.

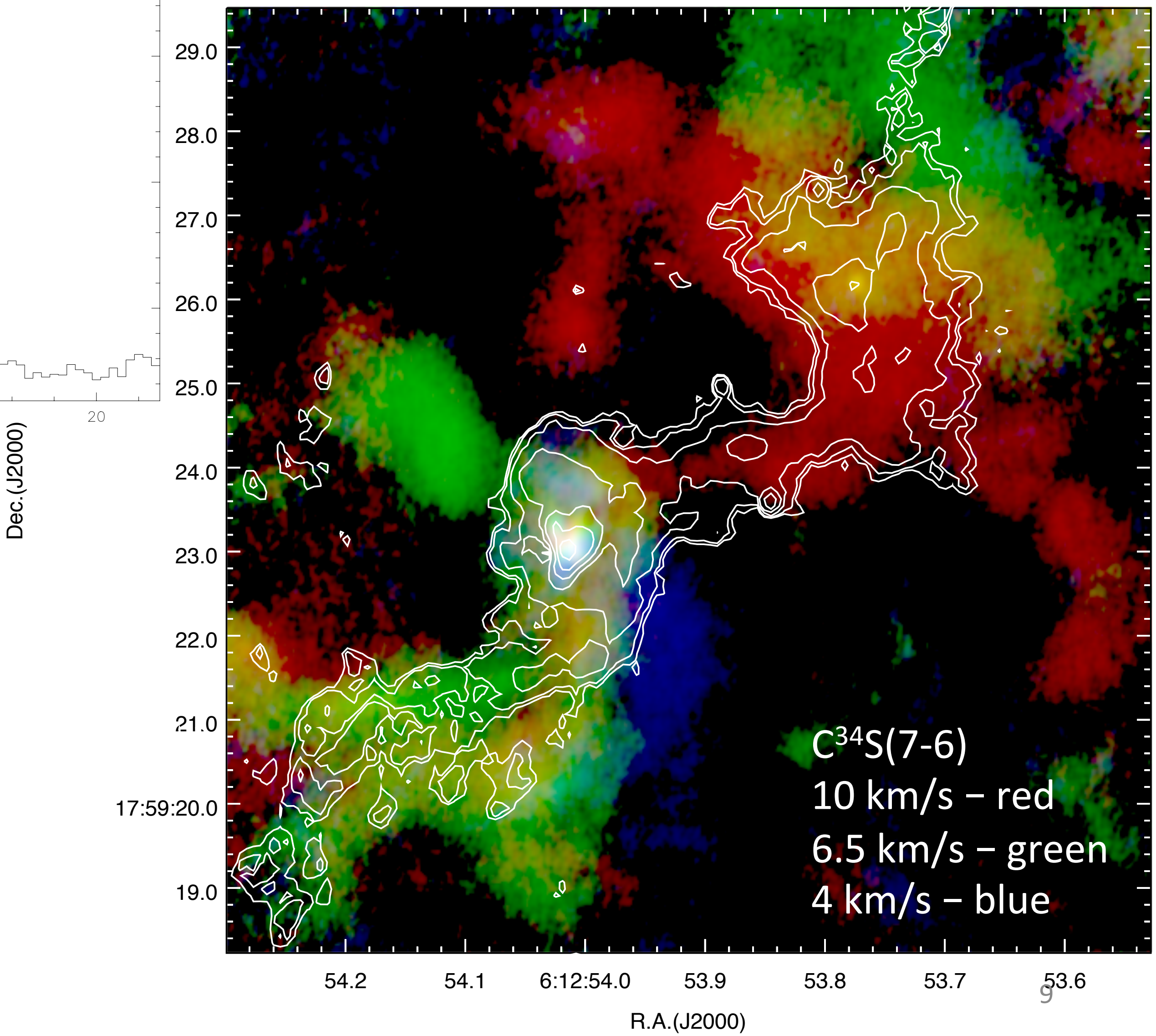


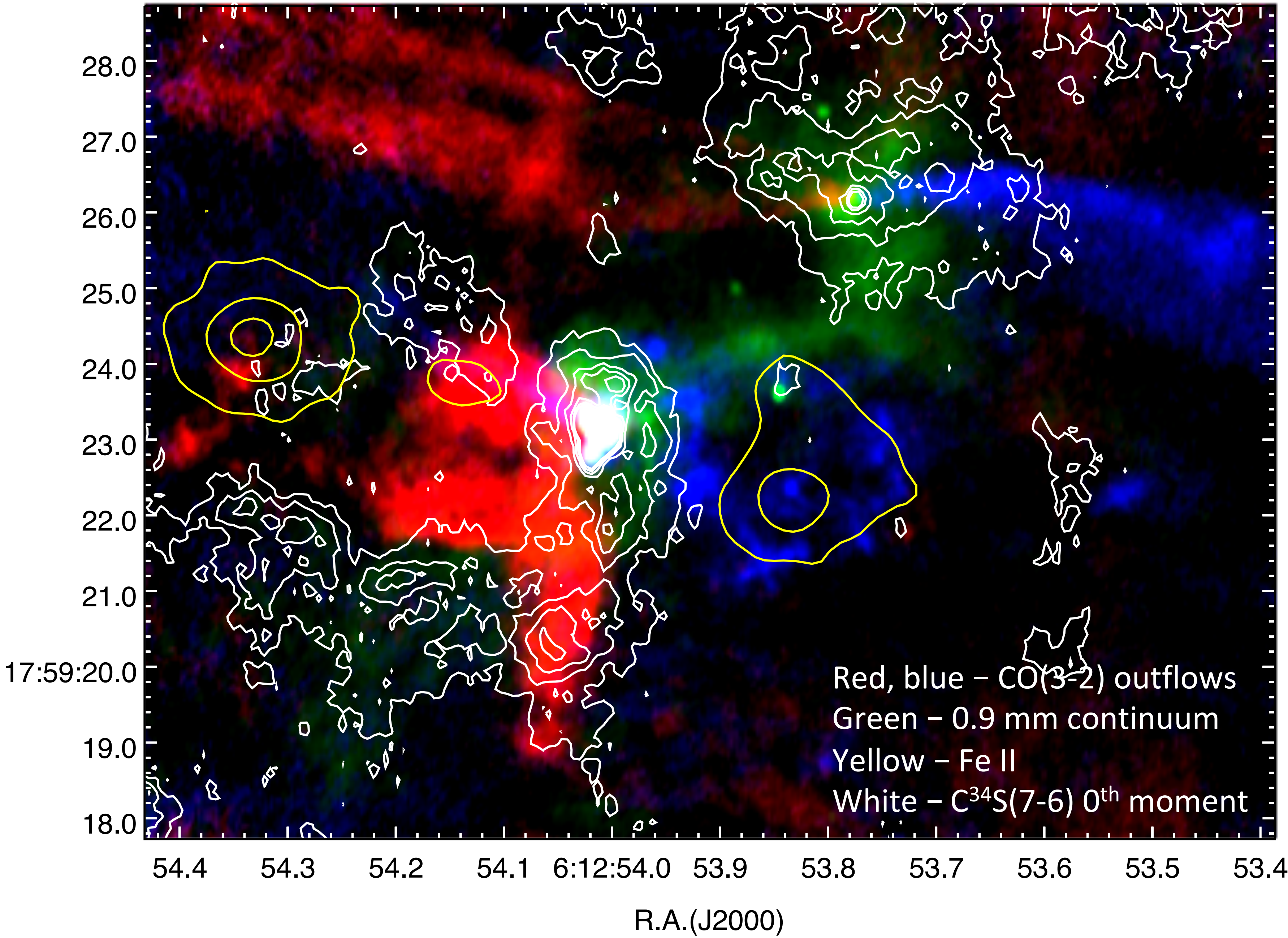
0.9 mm cont
SMA1
SMA2
SMA3
C1
C2
C3
P1
P2
P3
P4
P5
P6
Dec.(J2000)
R.A.(J2000)
29.0
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
17:59:20.0
54.2
54.1
6:12:54.0
53.9
53.8
53.7
53.6
Brightness temperature (K)
Offset ('')
C1
C2
C3
$C^{34}S(7-6)$
Brightness temperature (K)
V_{LSR} (km/s)

ALMA $C^{34}S$(7-6) data



The average $C^{34}S$(7-6) spectrum




Red, blue – CO(3-2) outflows
Green – 0.9 mm continuum
Yellow – Fe II
White – C34S(7-6) 0th moment
Dec.(J2000)
R.A.(J2000)
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
17:59:20.0
19.0
18.0
54.4
54.3
54.2
54.1
6:12:54.0
53.9
53.8
53.7
53.6
53.5
53.4

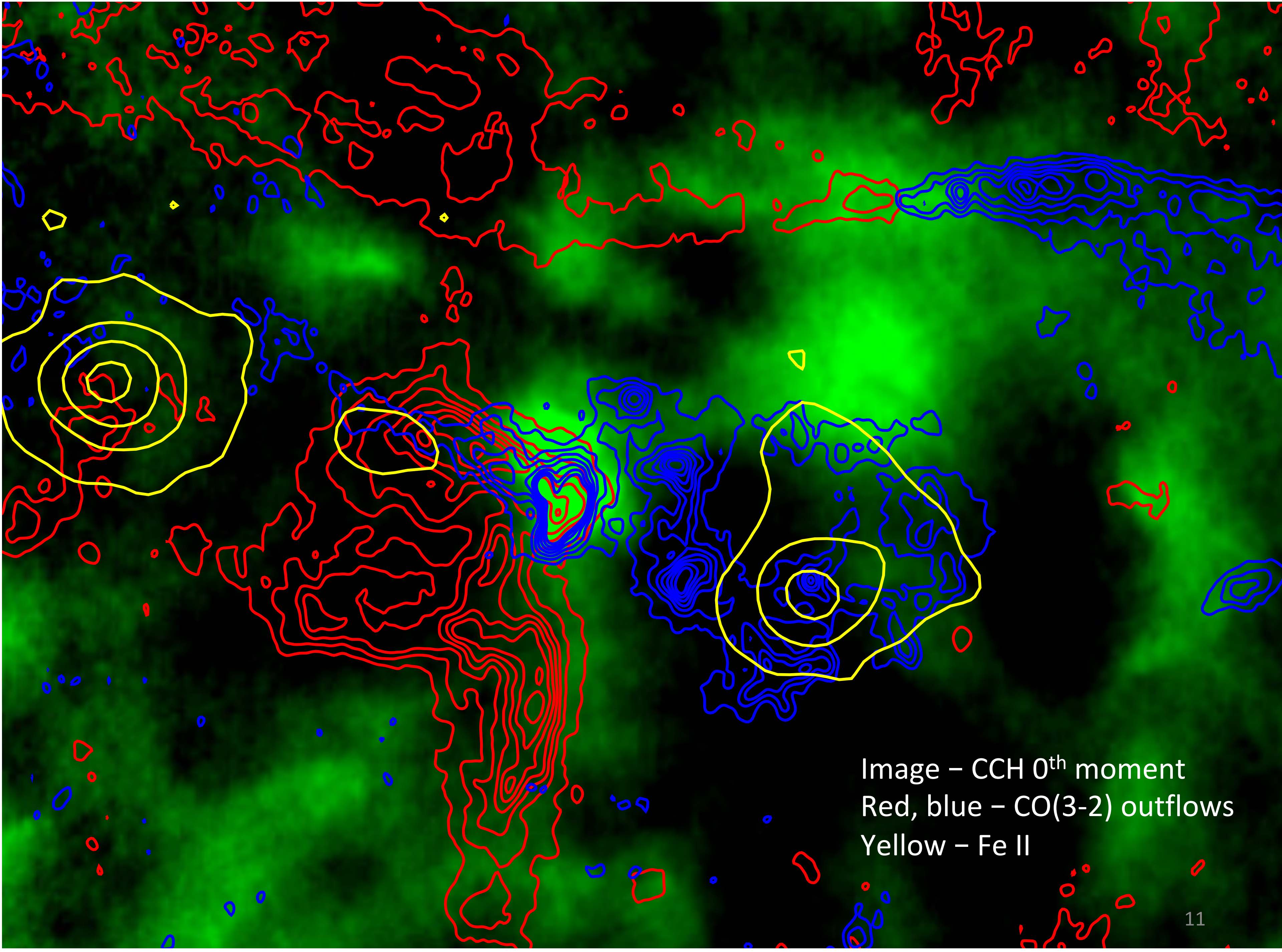
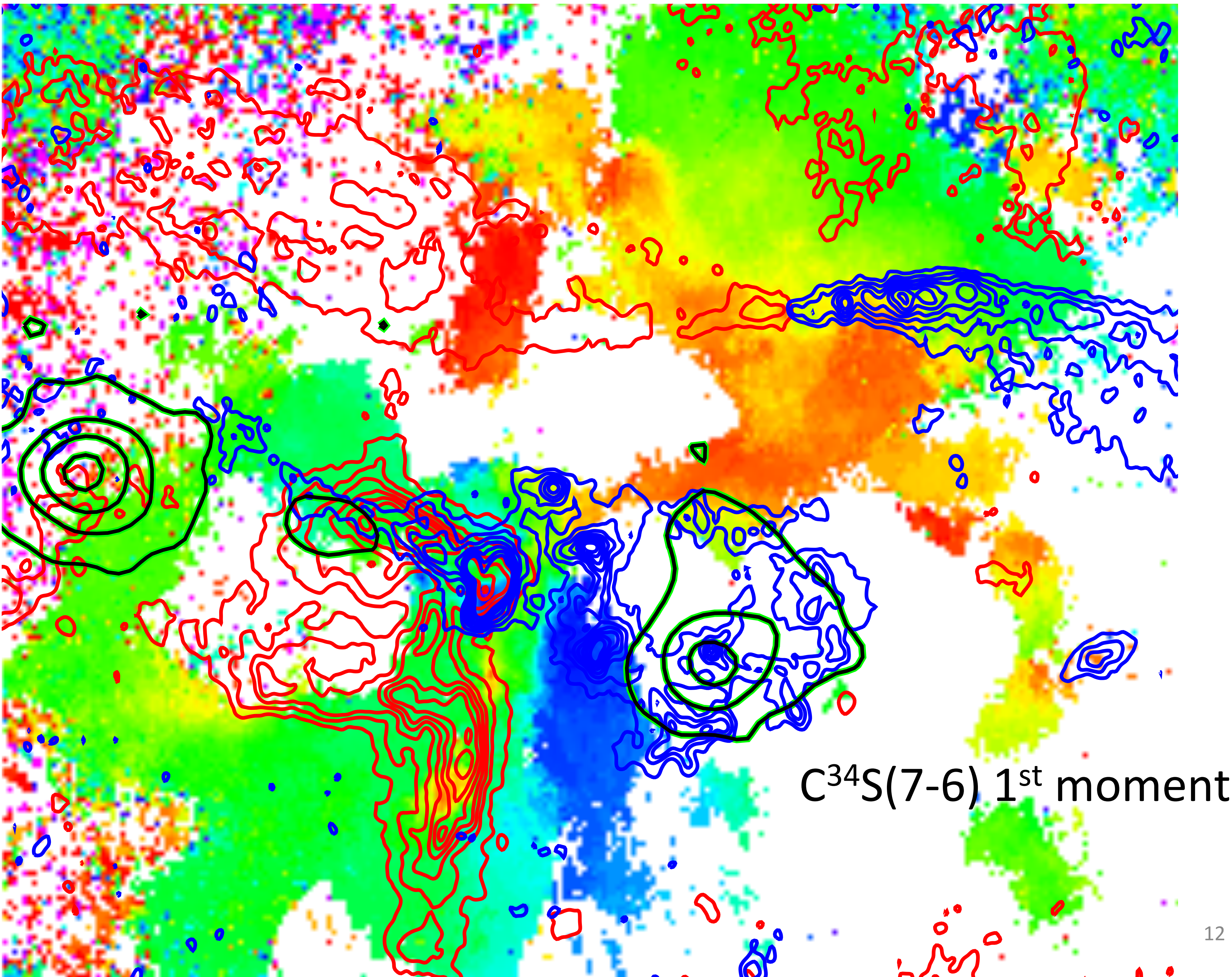


Image – CCH 0th moment
Red, blue – CO(3-2) outflows
Yellow – Fe II


$C^{34}S$(7-6) 1st moment

Physical properties

- Continuum "filament"

  $T_R(0.9\text{mm}) \approx 2-3\ \text{K} \quad \tau \sim 0.05\ \ \text{(assuming } T_d = 50\ \text{K)}$

  $N(H_2) \sim 7\times 10^{23}\ \text{cm}^{-2}$

  $n(H_2) \sim 3\times 10^{7}\ \text{cm}^{-3}\ \ \text{(assuming thickness=width)}$

  critical density for $\text{C}^{34}\text{S(7-6)}$ $n_{cr} \sim 10^{7}\ \text{cm}^{-3}$

  $M \sim 30\ \text{M}_\odot$

- Outflow

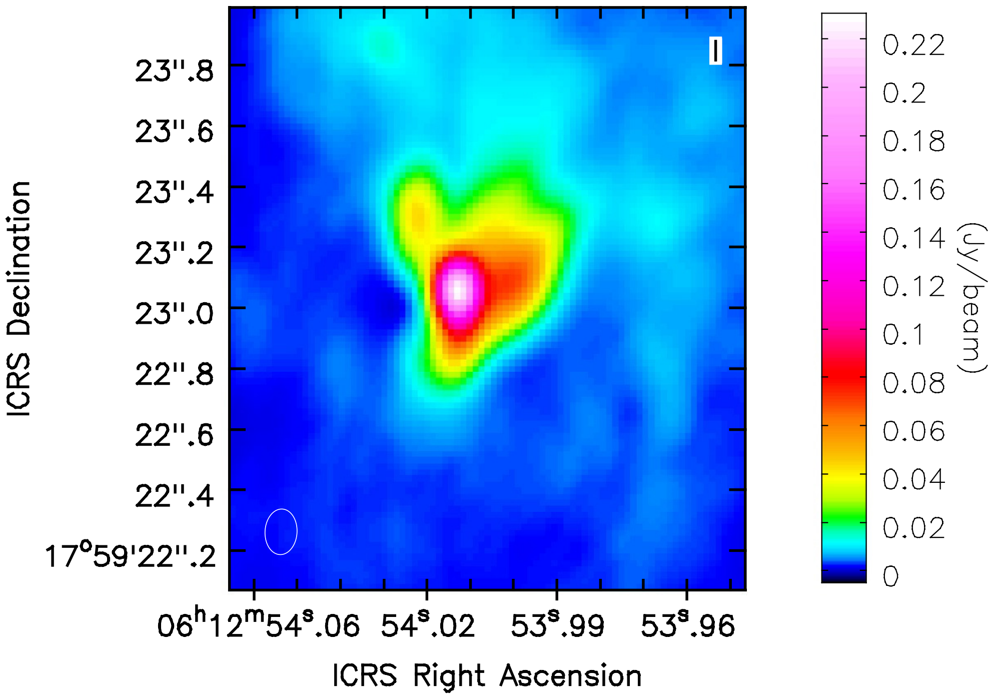
  age < 300 years, $n(H_2) \sim 5\times 10^{5}\ \text{cm}^{-3}$

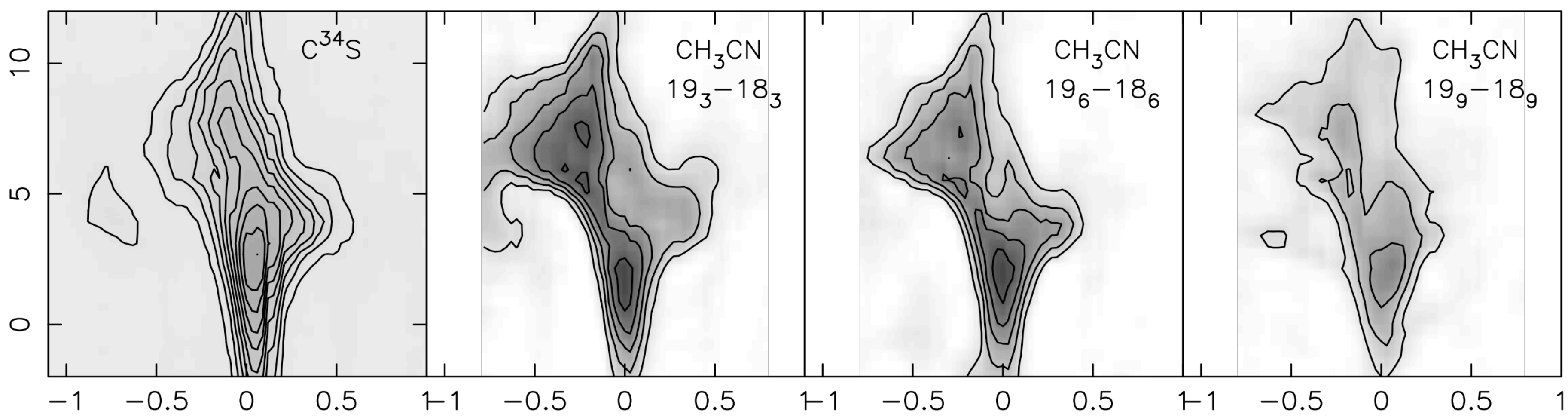
- Walls

  $T \sim 100$ K (?, implied by the high CS abundance)

  $\sigma_v(\text{C}^{34}\text{S}) \approx 0.5$ km/s (~ sound speed at 100 K)

SMA1 – signs of Keplerian rotation (ALMA data)





Submillimeter burst at 0.9 mm

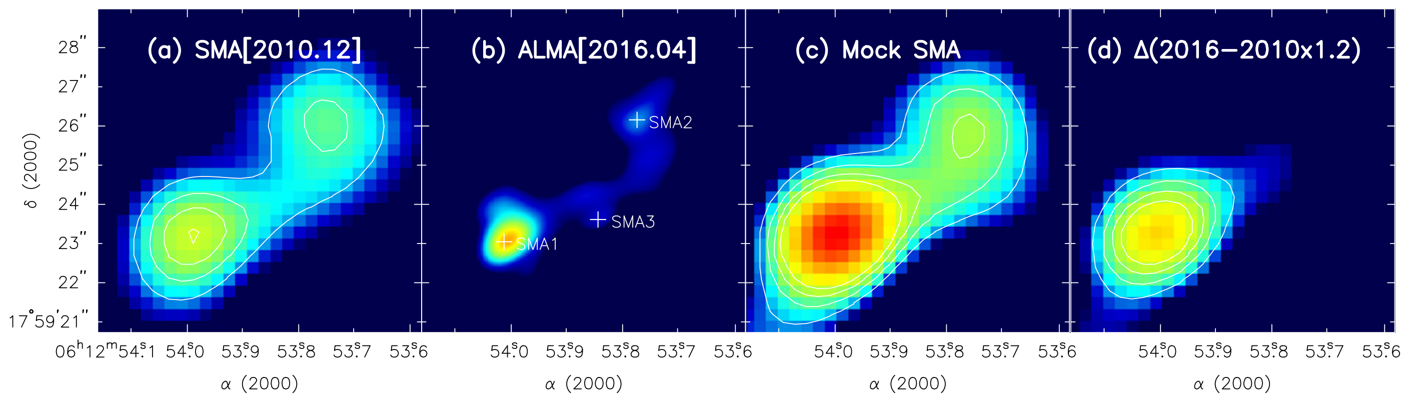


Figure 1. 900 μm continuum image of S255IR (a) observed in 2010 December by SMA at an angular resolution of $\sim 2''.0$. Contour levels are at 3, 5, 7, and 9 × 46 mJy/beam. (b) Observed in 2016 April by ALMA at an angular resolution of $\sim 0''.6$. The positions of SMA1–3 are marked by white crosses. (c) Made through mock SMA observations using panel (b) as the sky model. (d) The difference map made by first scaling panel (a) by 1.2 and subtracting that from panel (c). Contour levels in (c) and (d) are the same as (a), so does the false color scheme.

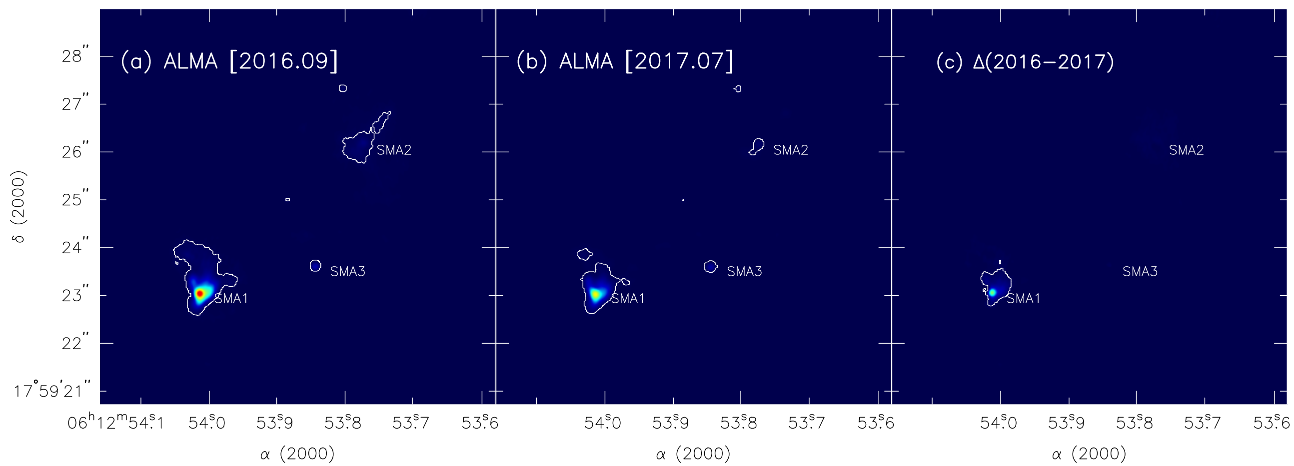


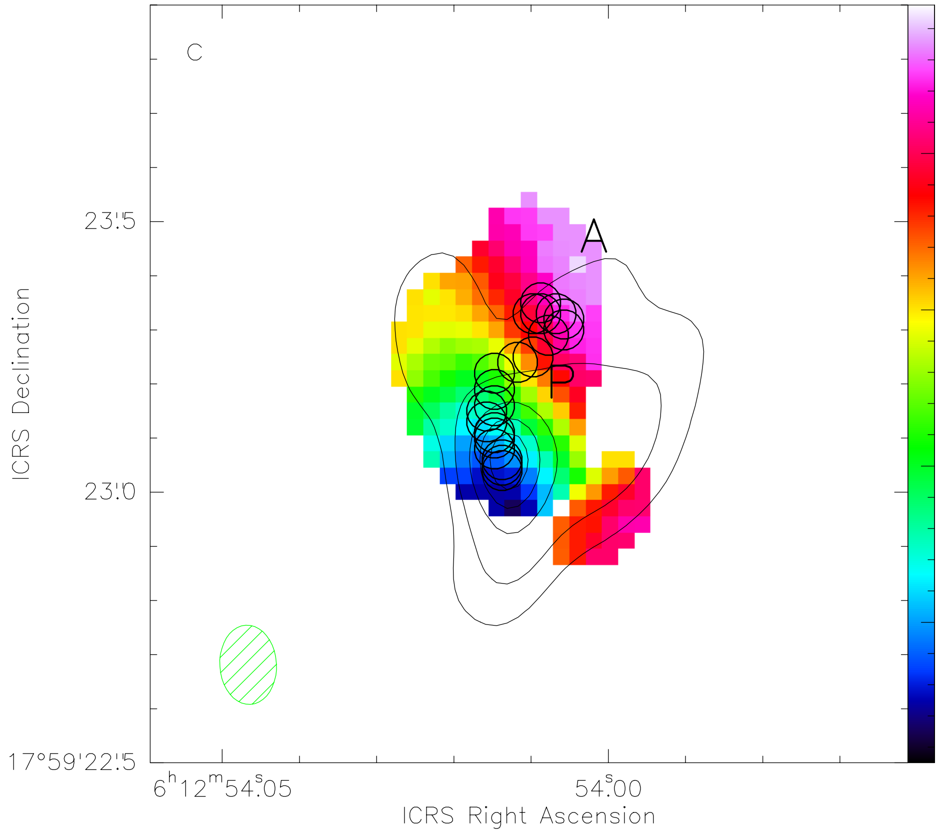
Figure 3. 900 μm continuum image of S255IR (a) observed in 2016 September by ALMA in false color at an angular resolution of $0''.14$. (b) Observed in 2017 July by ALMA at an angular resolution of $0''.14$. The contour and labels are the same as those in (a). (c) The difference map made by subtracting panel (b) from panel (a). The contour at 5-σ level marks the boundary of regions with significant emission and SMA1–3 are labeled in panel (a)–(c).

Liu, Su, Zinchenko et al. (2018)

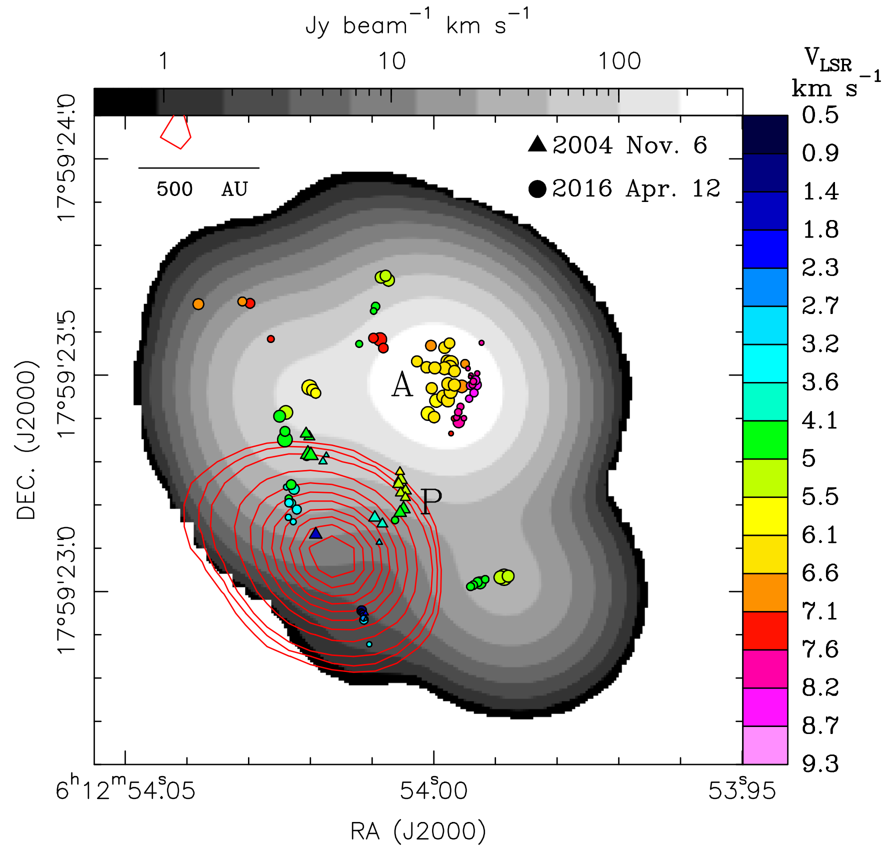
Burst parameters

- Both the intensity and flux density roughly doubled in 2016 as compared to 2010. This suggests an overall bolometric luminosity increase by a factor of about 16, which is larger than derived from SED by Caratti o Garatti et al. (2017) (~5.5). Their FIR data are taken at angular resolutions coarser than 6”, which may influence the results. Then, a 10% uncertainty in the flux density could lead to 40% uncertainty in the derived luminosity.
- In 2017 the intensity decreased by ~ 40%, which implies the burst duration ~ 2 years.

Masers in S255IR at 349.1 and 6.7 GHz



Probably this is a Class II methanol maser. The maser emission arises apparently in a ring at several hundred AU from the star (Zinchenko et al. 2017).



6.7 GHz methanol maser emission before (P) and after (A) the burst in 2015 (Moscadelli et al. 2017)

The decay of the maser at 349 GHz

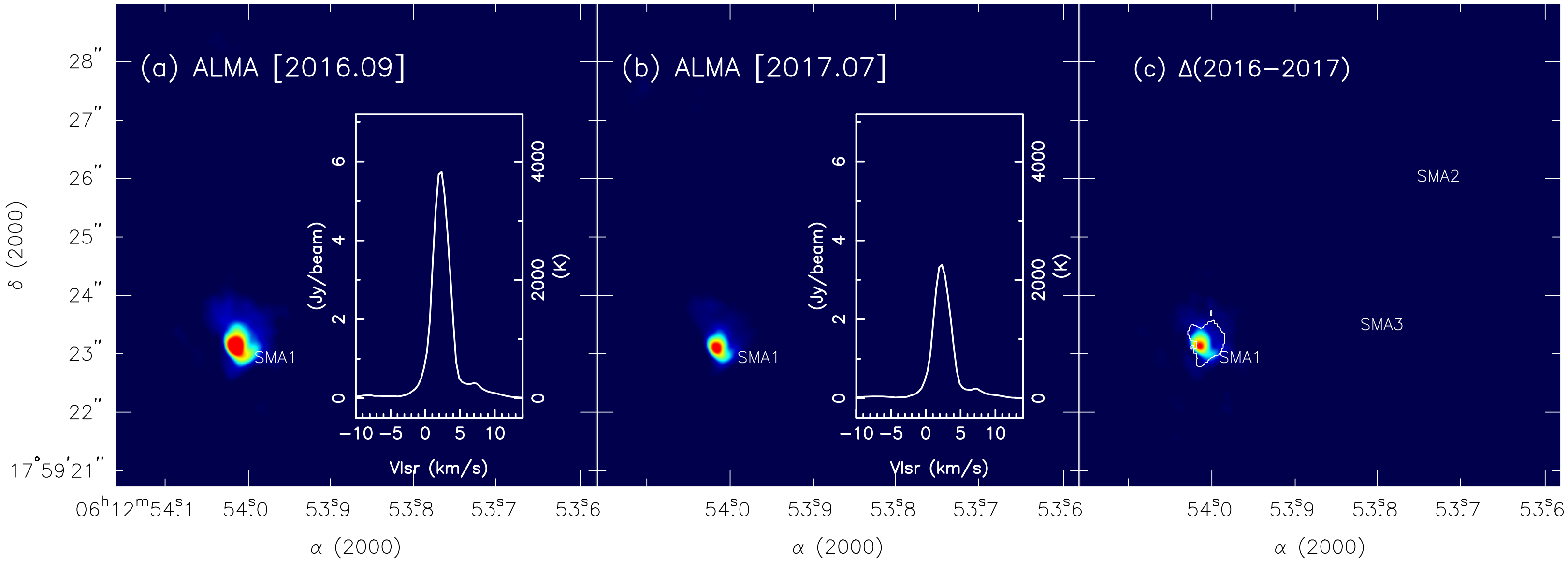


Figure 4. (a) Integrated intensity map of the 349.1 GHz CH_3OH $14_1-14_0A^{-+}$ maser emission observed by ALMA in 2016 September. An inset in the panel displays the CH_3OH spectra at its peak position. (b) The integrated intensity map of the same maser emission observed by ALMA in 2017 July. An inset, same as in panel (a), displays the peak position spectra. (c) The difference CH_3OH maser map made by subtracting panel (b) from (a). The contour delineates the region with excess 900 μm continuum emission shown in Figure 3(c).

Liu, Su, Zinchenko et al. (2018)

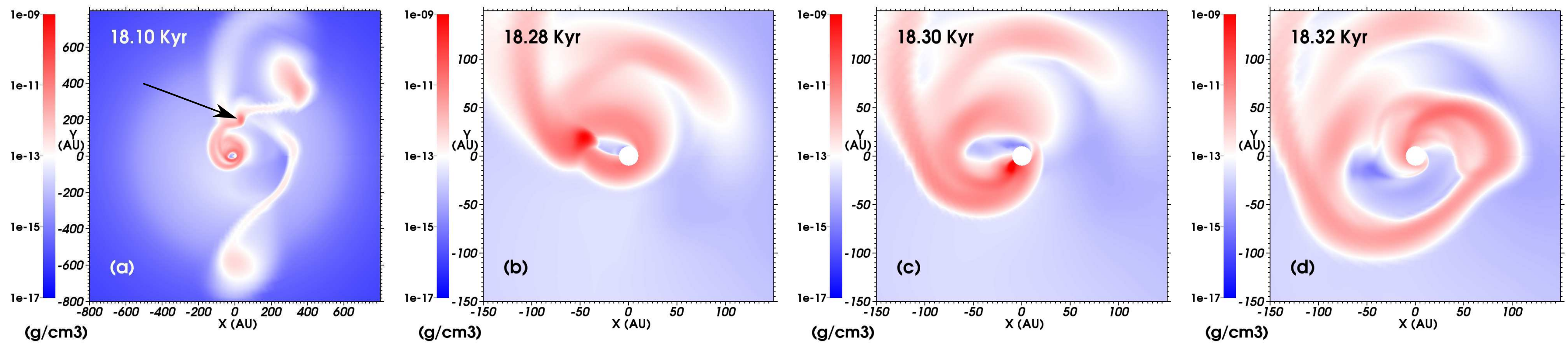


Figure 1. Midplane density in the center of the computational domain around the time of the first outburst. (a) The region within 800 AU when a clump forms in a spiral arm $\sim$ 200 AU away from the protostar, at a time 18.10 kyr. Panel (b-c) display zooms to illustrate the migration and accretion of a part of the clump at times 18.28, 18.30 and 18.32 kyr, respectively. The density is plotted in g/cm^3 on a logarithmic scale and the size of the panels is in AU.

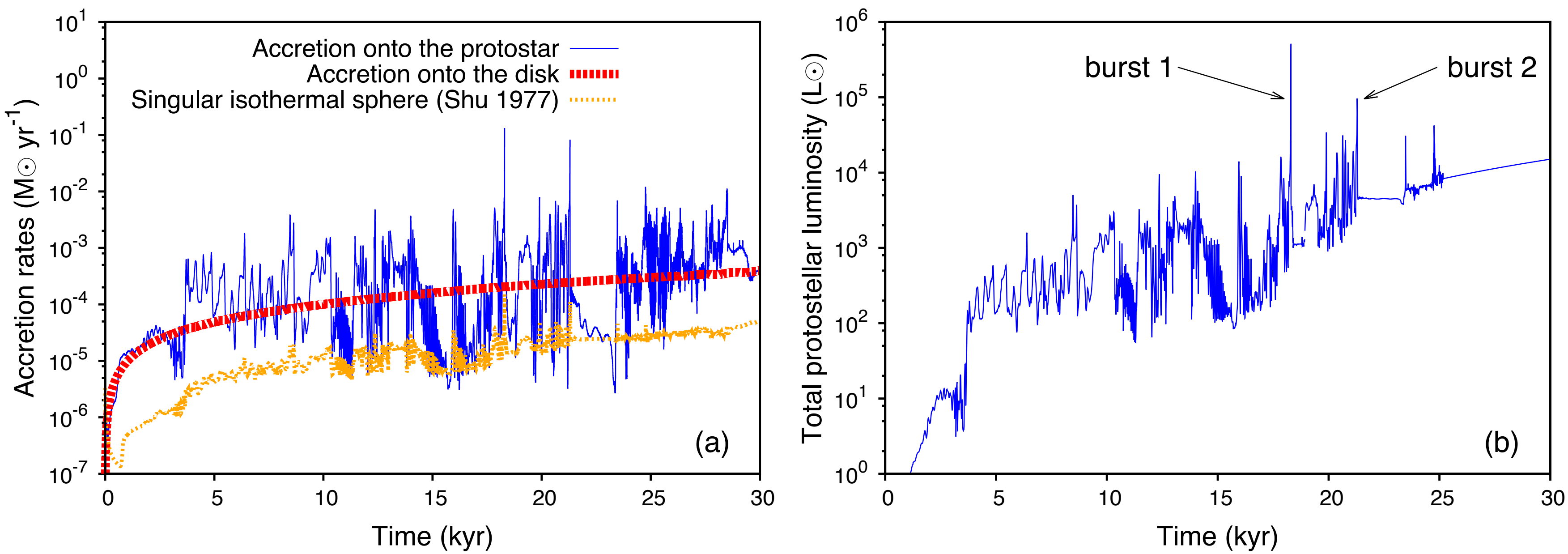


Figure 2. Left: accretion rate onto the protostar and mass infall rate onto the disc (in $M_\odot$ yr^{-1}). Right: total luminosity of the protostar (in $L_\odot$).

Conclusions

- The data show the presence of a narrow jet and a dense wide-angle molecular outflow from the 20 $M_{\odot}$ MYSO S255 NIRS3, surrounded by very dense and warm walls.
- A submillimeter burst of the S255IR-SMA1 was registered with the luminosity increase by an order of magnitude. Its duration is about 2 years.
- There are clear indications of episodic ejections from this object at the intervals of few hundred years (or even less). Some of the filamentary-looking structures could be created by the previous ejection events.
- In general, the results indicate an important role of the episodic disk accretion in the process of high mass star formation.

Thank you for attention!