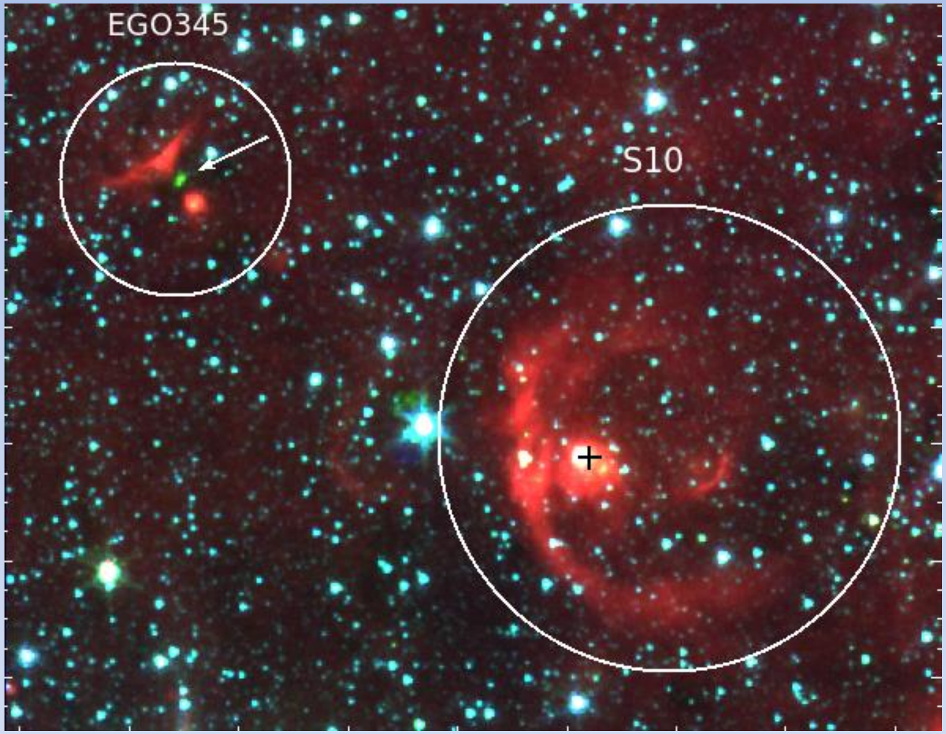
High-mass star formation
Infrared dust bubble – S10



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IISER, Tirupati

2nd BINA Workshop, Royal Observatory of Belgium, Brussels

12 October 2018

Spitzer Telescope Survey

Bubbling Disk!

Galactic Legacy Infrared Mid-plane Survey Extraordinaire (GLIMPSE)

IRAC instrument (3.6, 4.5, 5.8 and 8.0 μm , resolution ~2")

~ 600 bubbles catalogued by Churchwell et al. (2006, 2007)

~ 5000 bubbles catalogued by Milky way project (Simpson et al. 2012)

Infrared dust Bubbles

Churchwell et al. (2006, 2007)

Interesting morphological features (nearly spherical)

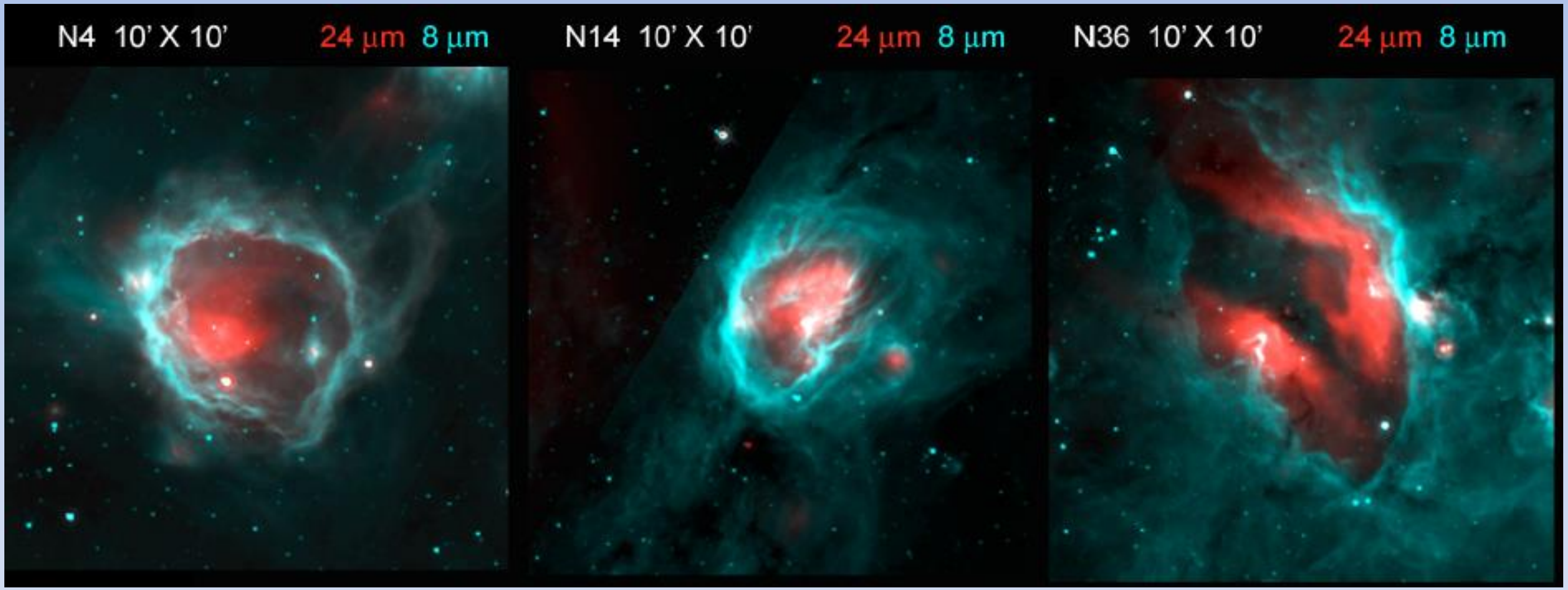
Bright-rimmed features in the mid-infrared

Appear as bright-rimmed 8μm shells that enclose 24μm emission (Spitzer images)

Associated with massive stars
Interaction of massive stars with the ISM

Sites of triggered star formation

Infrared dust Bubbles

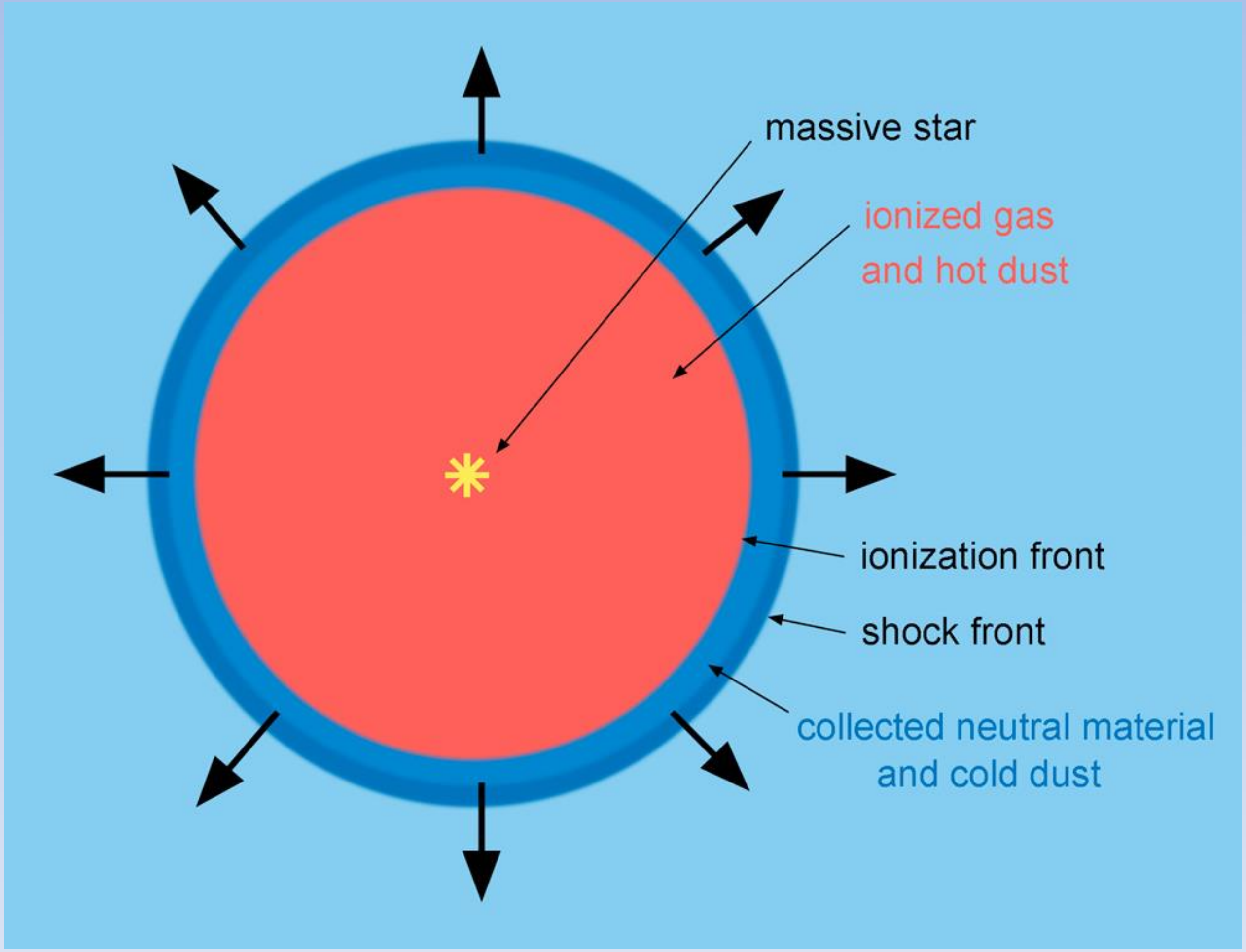


Deharveng et al. (2010)

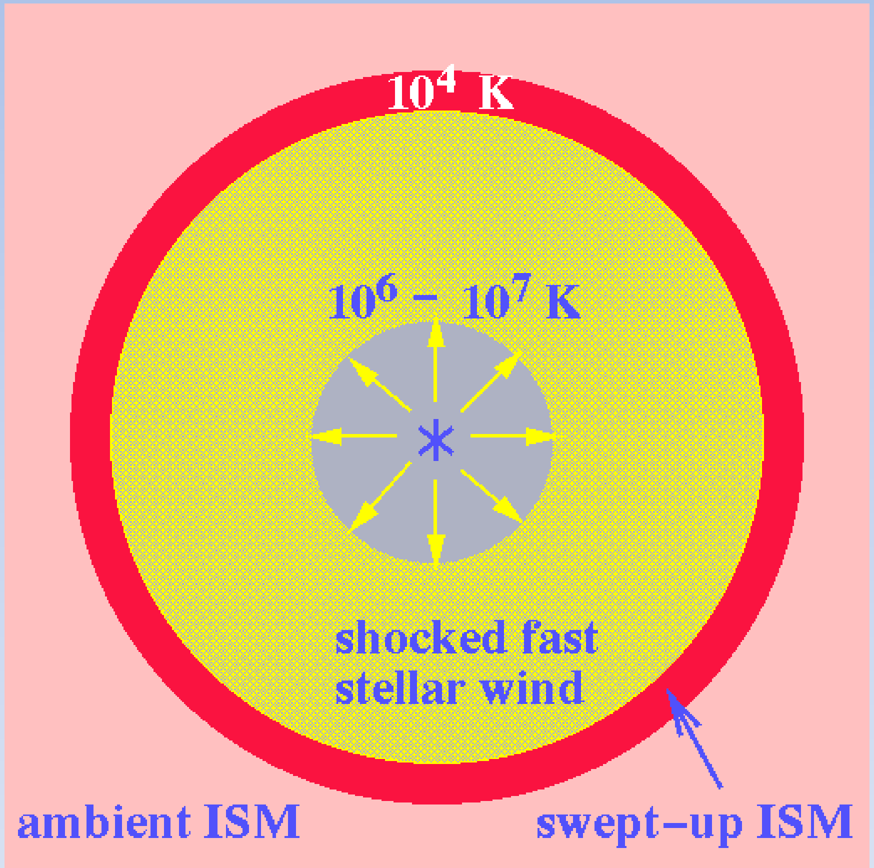
Why are these bubbles bright-rimmed in the MIR?

- These are due to the polycyclic aromatic hydrocarbons (PAHs) lines
- The excitation of these require substantial UV radiation
- Several vibrational mode of C-H and C-C stretching PAH features fall within the Spitzer-IRAC bands
- PAH emission - tracers of PDRs - destroyed in the interior

Formation – expanding HII region



Formation – Stellar wind



(Weaver et al. 1977)

Powerful winds of OB stars

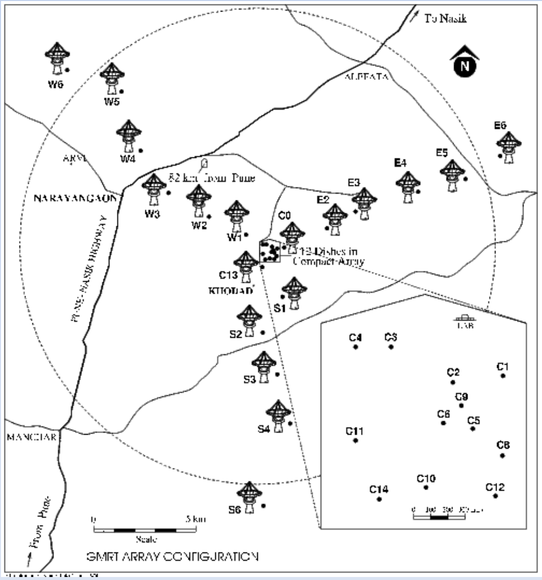
$\dot{M}_w \sim 10^{-6}\ M_\odot\ yr^{-1}$

$V_w > 1500\ km\ s^{-1}$

Shocked stellar wind T >10^6 K : expanding hot bubble

Expanding thin shell of shocked, swept-up ISM gas : T ~ 10^4 K

Radio Observations



GMRT (NCRA) – Narayangaon, Pune

Y – shaped configuration

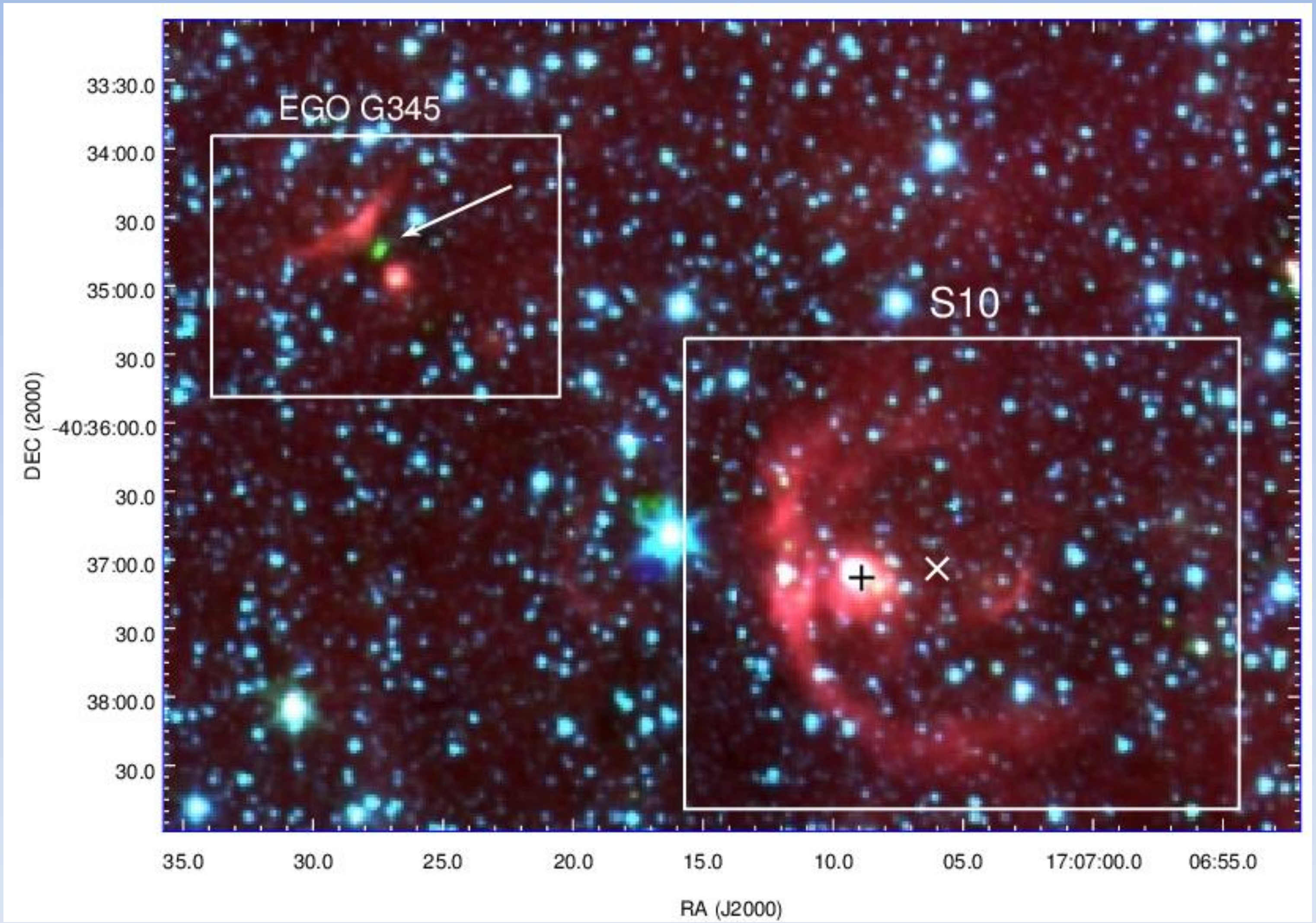
30 antennas (each 45 m in diameter)

Largest baseline ~ 25 km (highest resolution)

Shortest baseline ~ 100m (diffused emission)

Data reduction was carried out using **AIPS**

S10 and EGO G345.99-0.02 (EGO 345)



S10 and EGO G345.99-0.02 (EGO 345)

S10 is southern Galactic bubble with broken morphology (Churchwell et al. 2006).

The bubble is associated with IRAS 17036-4033.

Kinematic distance to the bubble is 5.7 kpc (Beltran et al 2006).

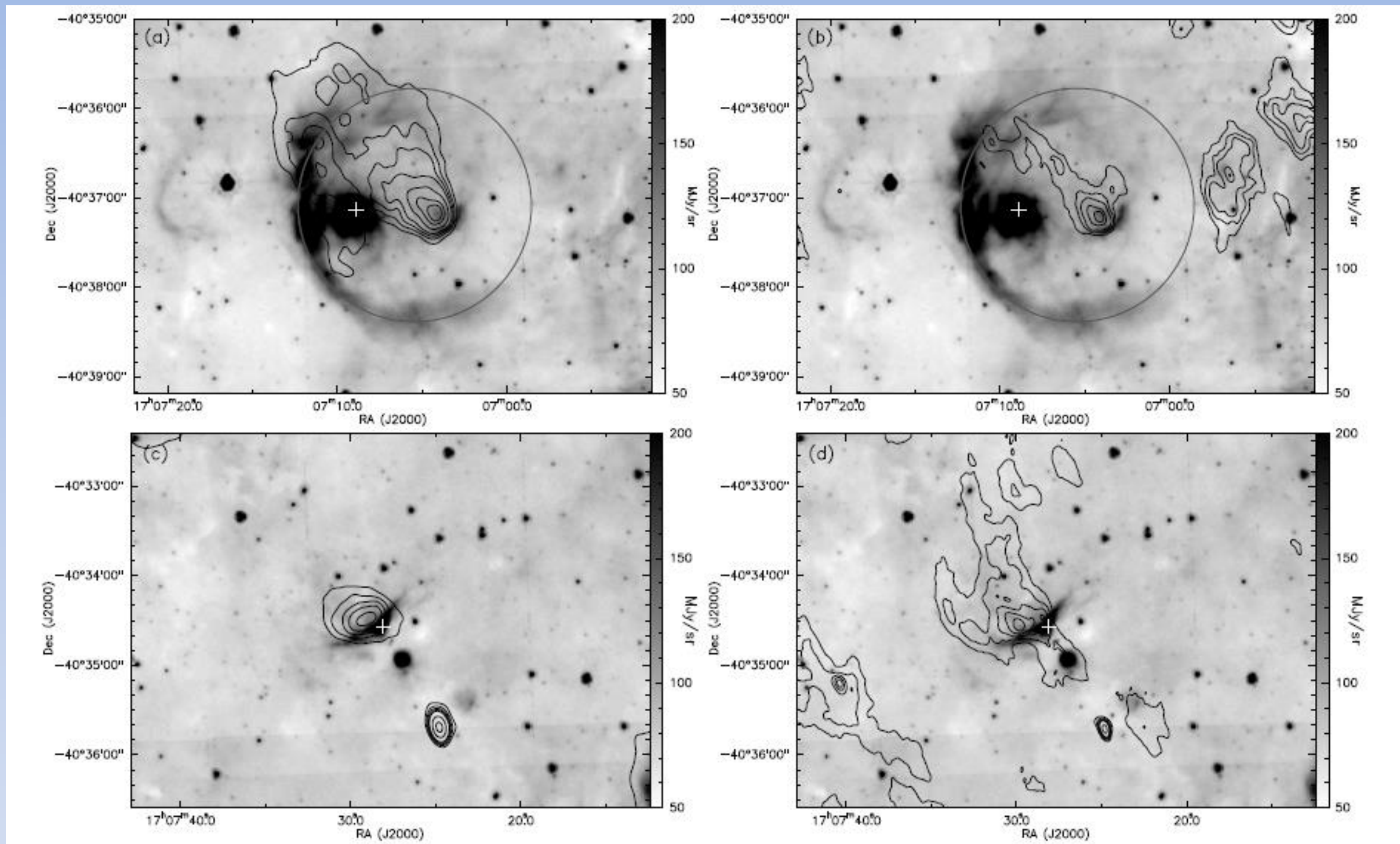
G345.99-0.02 is an Extended Green Object (EGO).

It is associated with IRAS 17039-4030

Shows association of Class I and II methanol masers.

Kinematic distance to the source is 5.6 kpc (Chen et al 2011).

Ionized emission

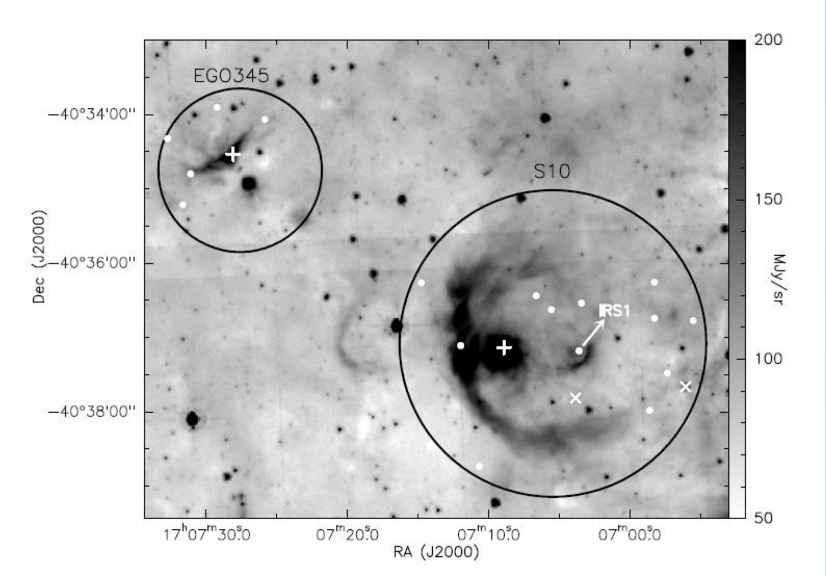


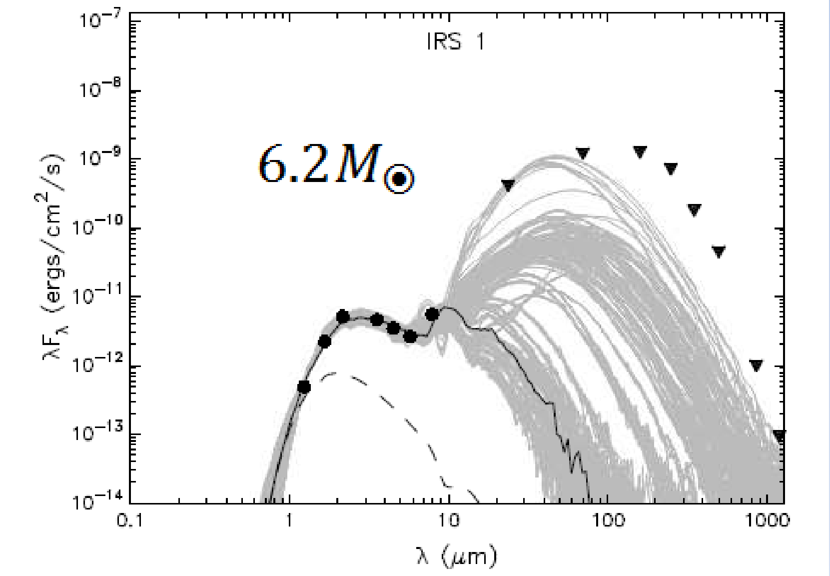
- Steep density gradient, with enhanced emission towards center
- Extended fan like morphology seen at 610 MHz compared to 1280 MHz
- Ionized emission seen to flow in NE direction from center

extent of the bubble S10. The '+' marks indicate the position of the IRAS point sources associated with both the regions.

Assuming optically thin free-free emission and a single source responsible for the ionized emission, the spectral type was of the ionizing star was found to be

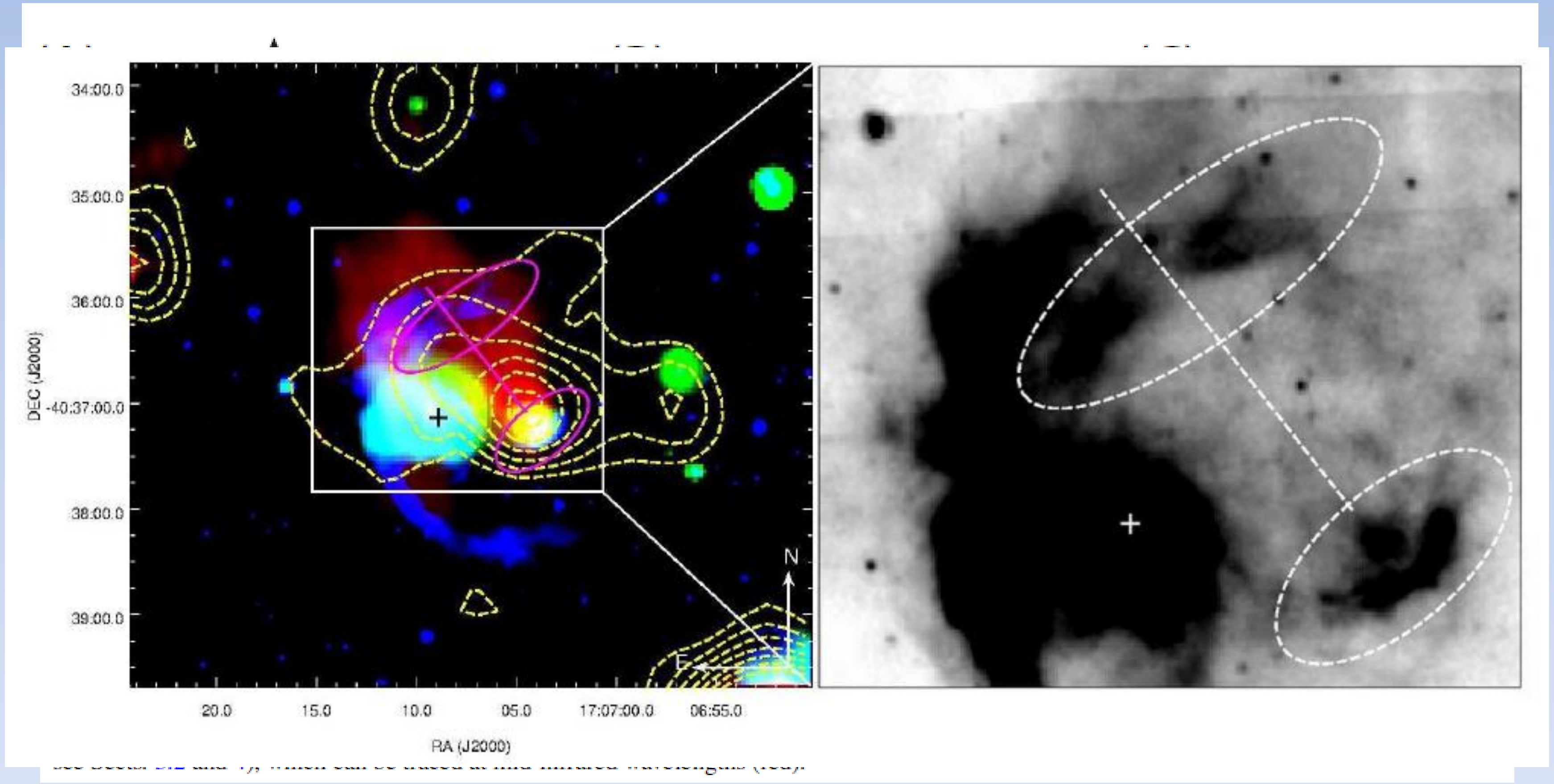
B0.5 – B0 for S10
B0 – O9.5 for EGO345





Exciting source possibly deeply embedded

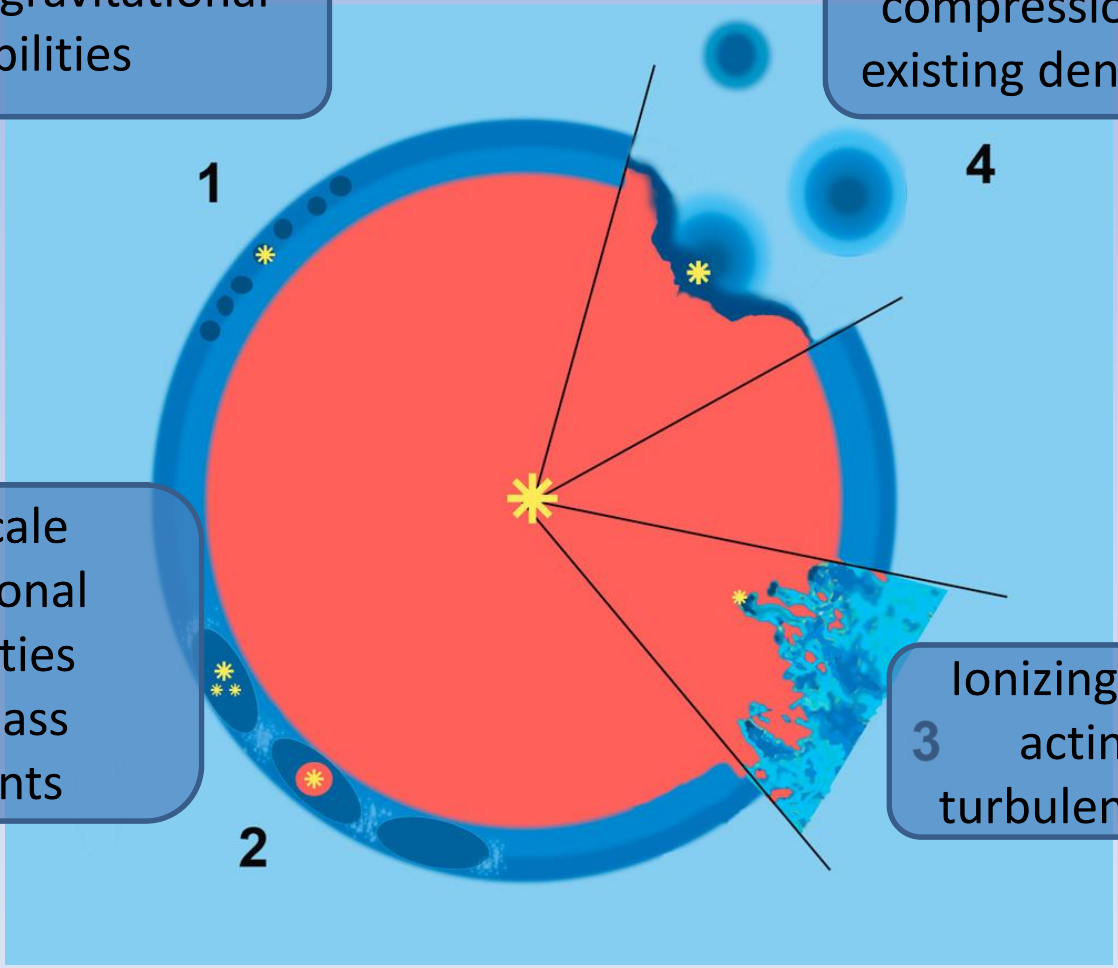
Possible dust wave in S10?



Triggered star formation

small-scale gravitational instabilities

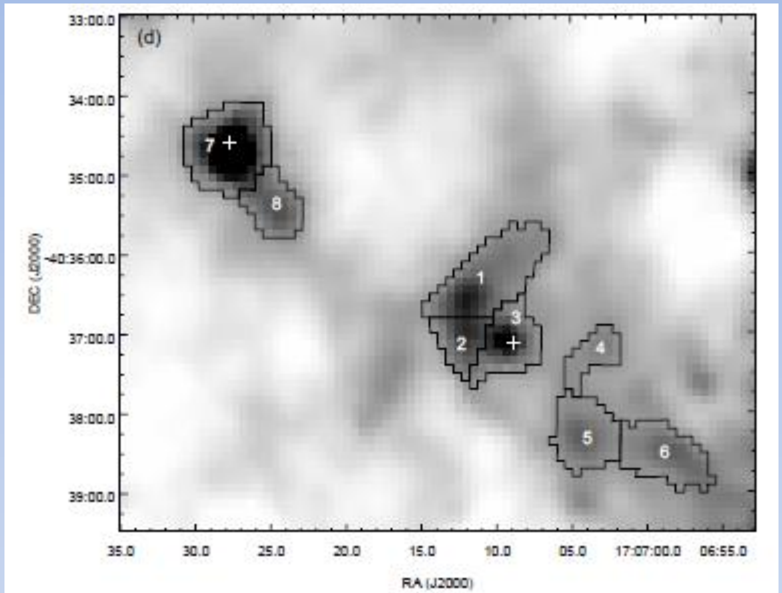
radiation-driven compression of pre-existing dense clumps



large-scale gravitational instabilities high-mass fragments

Ionizing radiation acting on a turbulent medium

Dust clumps and their properties



$$M_{\text{clump}} = \mu_{\text{H}_2} m_{\text{H}} A_{\text{pixel}} \Sigma N(\text{H}_2)$$

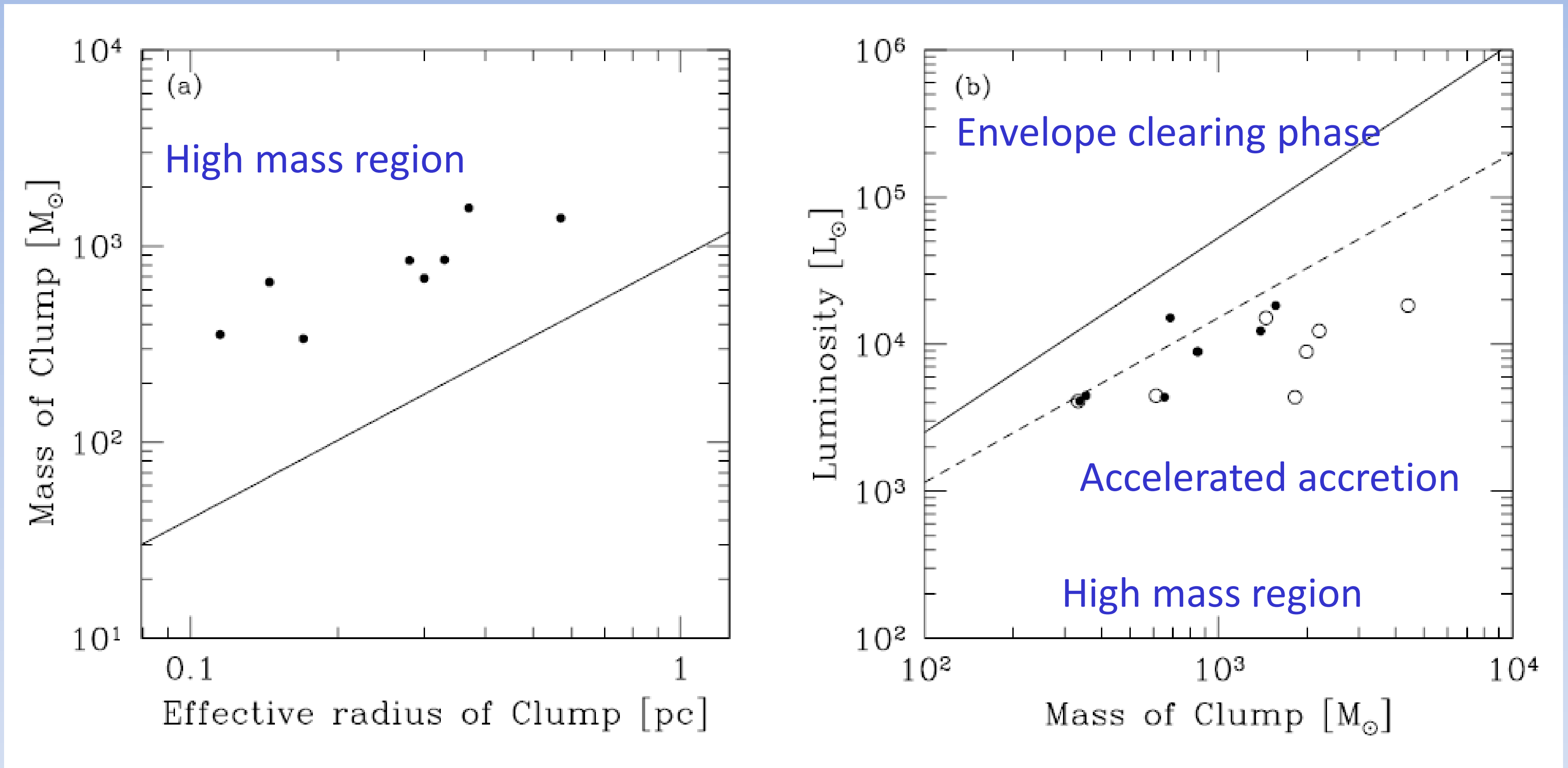
Clump No.	RA (2000) (hh:mm:ss.ss)	DEC (2000) (dd:mm:ss.ss)	F_{250} (Jy)	Linear Diameter (pc)	Mean T_d (K)	Mean $N(\text{H}_2)$ ($\times 10^{22} cm^{-2}$)	M_{250} ($\text{M}_\odot$)	$\sum N(\text{H}_2)$ ($\times 10^{23} cm^{-2}$)	M_{CD} ($\text{M}_\odot$)
				S10					
1	17:07:12.02	-40:36:33.00	222	1.1	20.6	2.0	1436	4.2	1390
2	17:07:12.02	-40:36:57.00	85	0.2	20.8	1.7	533	1.1	354
3	17:07:09.40	-40:37:09.09	131	0.6	21.5	1.7	750	2.1	685
4	17:07:03.08	-40:37:15.40	63	0.3	21.0	1.6	390	1.0	337
5	17:07:04.70	-40:38:27.90	134	0.6	20.5	1.8	875	2.5	845
6	17:06:58.90	-40:38:27.60	143	0.7	19.6	2.1	1074	2.6	852
				EGO345					
7	17:07:27.77	-40:34:44.05	283	0.7	21.0	2.3	1754	4.7	1564
8	17:07:24.63	-40:35:26.24	99	0.3	19.4	2.2	770	2.0	655

Dust clumps and their properties

Clump No.	M_* ($M_\odot$)	$\dot{M}_{env}$ (10^{-3} $M_\odot$ yr^{-1})	M_{env} ($M_\odot$)	Luminosity (10^3 $L_\odot$)
		S10		
1	12 – 22 (19.7)	5 – 9 (9.2)	2000 – 5000 (2200)	6 – 15 (12.3)
2	9 – 14 (10.8)	2 – 7 (5.0)	400 – 2000 (613)	2 – 6 (4.5)
3	11 – 22 (11.7)	2 – 9 (2.3)	1000 – 2000 (1450)	10 – 31 (15.1)
4	8 – 12 (11.8)	1 – 5 (3.3)	100 – 700 (333)	2 – 9 (4.1)
5	11 – 18 (17.8)	3 – 7 (6.9)	600 – 2500 (1990)	4 – 10 (8.9)
6	12 – 18 (17.8)	4 – 7 (6.9)	2000 – 5000 (1990)	4 – 9 (8.9)
		EGO345		
7	15 – 25 (24.8)	5 – 10 (9.3)	2000 – 5000 (4410)	11 – 26 (18.3)
8	10 – 14 (11.5)	2 – 6 (5.1)	600 – 3000 (1820)	2 – 6 (4.4)

All clumps harbour massive stars with high accretion rates

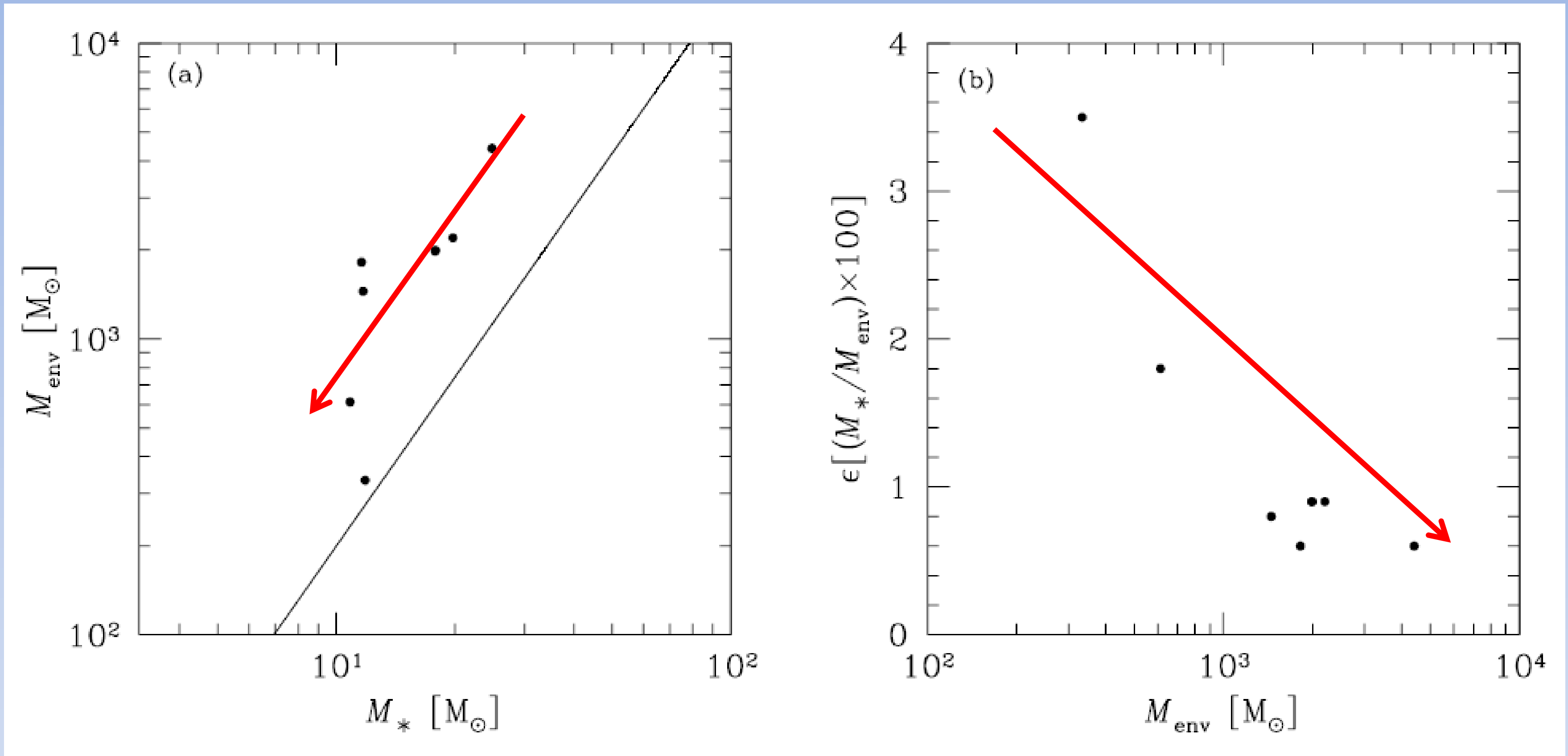
Nature of dust clumps



R-M relation from Kauffmann et al. (2010)

M-L relation from Molinari et al. (2008)

Nature of dust clumps



Final mass of star displays a trend with initial mass of the envelope

Star formation efficiency 0.6 – 3.5%

In conclusion

The first high-resolution and low-frequency radio continuum map of S10 suggest the excitation by a B0.5 – B0 massive star.

The formation could be attributed to thermal overpressure in the bubble interior – detection of a possible bow-wave – first in the IRAC bands.

Dust clumps associated with S10 and EGO345 are potential high-mass forming clumps in possibly the accelerated accretion phase.

Expected final stellar masses show a good correlation with the initial mass of the clumps – negates Competitive Accretion.

Thank you!

Collaborators: A Tej, S Vig (IIST), Ishwara Chandra CH, SK Ghosh (NCRA-TIFR)

Indian Institute of Space Science and Technology

Trivandrum – KERALA – INDIA

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