NIR and MM observations of the globulettes in the Rosette Nebula

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Introduction

Globulettes are gas/dust clumps seen optically in silhouette against bright nebular background in HII regions. They have most likely detached from eroding elephant trunks in expanding HII regions. Globulettes form a class of objects whose shape resembles that of starless globules but their size is considerably smaller with masses ranging from 1 to about 500M_{Jup}. In the Rosette Nebula, the globulettes have sizes of ~2-25''. Some have optically bright rims facing the central cluster and some have developed tails pointing away from the cluster. Our aim is to determine the evolution and the physical characteristics such as mass, density, and velocity of the globulettes observed in the Rosette Nebula which is rich in globulettes. We also study possible cases of star formation in the globulettes and their environment.

Observations

The northwestern region of the Rosette Nebula was imaged in NIR JHK_S, narrow Paschen β, 2.09, and H_2 2.12 μm filters with the NTT/SOFI. ^{12}CO and ^{13}CO (1-0), (2-1), and (3-2) observations of selected globulettes were done with the APEX 12m and Onsala 20m radio telescopes. The CO and some of the NIR observations were reported in Gahm et al. 2013 (GPMH13). Spitzer IRAC and MIPS (3.6-8.0 μm and 24&70 μm) archival images were also obtained.

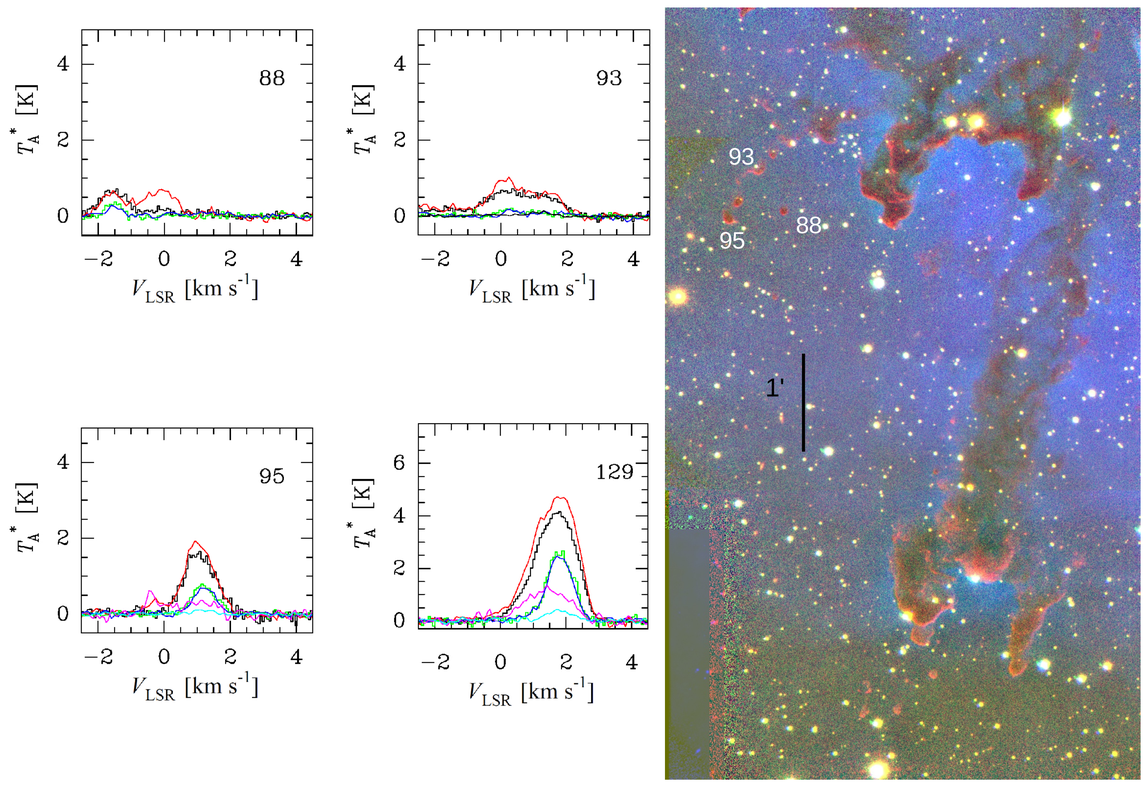

Fig. 2. *Left:* CO spectra obtained towards the globulettes in the T_A^* scale. The ^{12}CO (3–2), (2–1) and (1–0) spectra are plotted in black, red and magenta, respectively. For the ^{13}CO spectra the colours are green, blue and cyan. The ^{12}CO and ^{13}CO (3–2) spectra are plotted as histograms. *Right:* The "Claw" and "Wrench" trunks (upper and lower, respectively) in a false-color H_2 (red), Pβ (green), Hα (blue) image. Several small globulettes are seen south of the Wrench and in a prominent string-like feature east of the Claw.

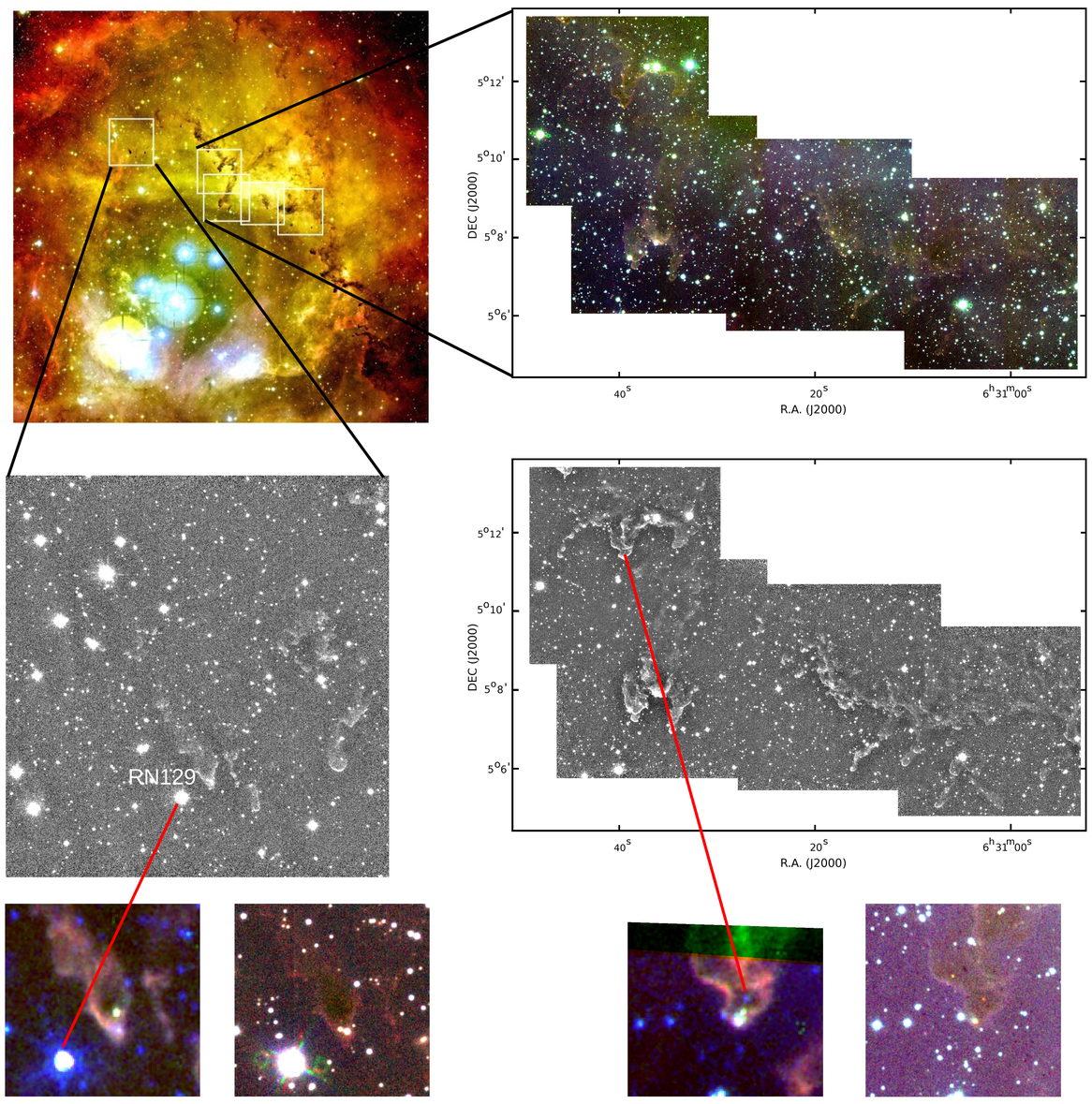

Fig. 1. *Upper left:* The Rosette Nebula in Hα (red) and OIII (green) (credit: Canada-France-Hawaii Telescope). White boxes show the five observed 4.5' by 4.5' NIR fields. *Upper right:* The northwestern part of Rosette Nebula in a false-color K_S (red), H (green), and J (blue) image. The large elephant trunks "Claw" and "Wrench" are seen in the upper left and lower left, respectively. *Middle left:* The separate field F19 imaged in the narrow H_2 filter at 2.12 μm. *Middle right:* The northwestern shell imaged in the H_2 2.12 μm filter. *Lower left pair:* Globulette RN129 imaged in Spitzer 8.0 (red), 5.8 (green), 3.6 μm (left) and K_S (red), H (green), and J (blue) (right). *Lower right pair:* The tip of the eastern elephant trunk in Claw (filters as for RN129).

Results & conclusions

The largest globulettes and some of the small ones are seen in absorption against both the Pβ and Hα emission. In these filters the apparent sizes of the globulettes are very similar (Fig. 2, right). This indicates that even the small globulettes can be dense and that the density is high already at the outer edge of the globulettes. The A_v in the globulette heads can be estimated from the reddening of single background stars with the NICER method. Using a normal interstellar redding law the A_v is ~3-10^{mag}. The typical density of $n(H_2)$ ~10^4 cm^{-3} of the heads is supported by simulations in GPMH13. In some cases the heads of the globulettes are trailed by a less dense tail.

The JHK_S and Spitzer images (Fig. 1, lower) suggest that star formation is going on in the most massive globulette, RN129, and in one elephant trunk (the Claw). Also, south of the the Wrench is a main sequence star which has been formed inside the trunk based on its location close to the rim and the faint surface emission detected at 2.09 μm. An optical spectrum collected by Gahm indicates this is a A0 star.

The H_2 emission reveals thin bright rims in the trunks and most of the globulettes (Fig. 1, middle). The rims are close behind the Hα front, suggesting that the hydrogen is in molecular form just beneath the cloud surface. No surface brightness in the trunks nor the globulettes is observed in the narrow 2.09 μm continuum filter. A comparison of the globulette rims in the H_2 and K_S images reveals that the H_2 2.12 μm emission covers about a third of the observed K_S emission. The remaining two-thirds is line emission from other lines inside in the K_S band. The thin layer of fluorescent H_2 emission on the surface of the globulettes resembles the fluorescent H_2 emission detected in the Eagle Nebula (Allen et al. 1999).

The CO lines in the globulettes are narrow, ~1.0 km/s. Some spectra show signs of blue-shifted emission in the globulette tails. The velocity dispersion in the globulettes and shell is small, 0.5±2.1 km/s, which indicates that the globulette system and the northwestern shell of the Rosette Nebula expand with the same radial velocity away from the central cluster. Simulations done by GPMH13 on the CO data and estimates based on optical imaging by Gahm et al. 2007 estimate the range of globulette masses as ~1-800 M_{Jup}.

References: Allen, Burton, Ryder, Ashley, Storey, 1999, MNRAS, 304: 98.
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