A Study of the Cometary Globules in the Gum Nebula

A *Thesis submitted*
for *the degree* of
Doctor of Philosophy
in *the Faculty* of *Science*

by

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Declaration

I hereby declare that the work presented in this thesis is entirely original, and has been carried out by me at the Raman Research Institute under the auspices of the Department of Physics, Indian Institute of Science. I further declare that' this has not formed the basis for the award of any degree, diploma, membership, associateship or similar title of any University or Institution.

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To My Parents

One should not abandon one's duty suited to one's nature, *O Arjuna,* though it *may* be *imperfect;* for every enterprise is involved in *imperfection,* like fire *in smoke.*

-Bhagavadgita XVIII:48 (borrowed *from Arora)*

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Contents

A Summary of Main Results Presented in the Thesis

The first part of the thesis deals with the development of a *wide-band mechanically tuned local oscillator. using the Gunn diode* for use with the 10.4m millimeter-wave radio telescope at the Raman Research Institute. This provides sufficient power to efficiently operate two cryogenic Schottky mixers (dual polarisation) and tunes over the frequency range 75-115 GHz covering most of the 3-mm atmospheric transmission window (W-band). Rotational transitions of many astrophysically important molecules including CO fall in this range.

A study of the cometary globules in the Gum Nubula forms the second part. Among the smaller interstellar molecular clouds the Cometary Globules (CGs) stand out due to their peculiar morphology. They are characterised by compact, dusty heads with long faintly luminous tails extending on one side and narrow bright rims on the other side. There exists a significant population of such CGs in the Gum Nebula. The Gum Nebula is a large structure $\sim$ 12.5 parsec in radius delineated by Hα emitting filaments. The true nature of the Gum Nebula is ill understood; according to various conjectures it could be an old supernova remnant, or a bubble in the interstellar medium excavated by strong stellar winds from hot stars, or an evolved HII region. The CGs in the Gum Nebula are distributed over a region $\sim$ 80 parsec in radius with their tails pointing away from an apparent common center. In the visible region these globules have bright rims on the side facing the common central region. Some of the heads have embedded young stars. In the region bounded by the CGs there are a few massive hot stars including ζ Puppis believed to be the most luminous star in the southern sky. It has been suspected that the morphological appearance of the CGs may be due to the influence of these stars.

Although these globules have been known for more than a decade now there has been no satisfactory attempt to study their origin and kinematics. A detailed study was therefore undertaken using the 10.4 m millimeter-wave radio telescope at the Raman Research Institute. The study consisted of ^{12}CO observations of the heads and the tails of the CGs using the $J = 1 \rightarrow 0$ millimeter-wave rotational transition of the carbon monoxide molecule. In addition, the Globule No.22 was mapped in both ^{12}CO and ^{13}CO.

An analysis of tlic radial velocities obtained from the survey and the maps have led to the following findings:

1. The system of CGs is expanding with respect to a common morphological center at ~ 12 kms^{-1}. The expansion age is ~ 6 Myr.

2. Some of the tails observetl show systematic velocity gradients. If the tails were formed due to the elongation resulting from these velocity gradients then the estimated stretching age is ~ 3 Myr.

3. The mass of CG 22 is $\sim 27M_{\odot}$. Interestingly, if tlie cloud was in virial equilibrium then its mass must be $\sim 250M_{\odot}$.

There have been previous conjectures that the young stars embedded in the heads of some of the globules may have been formed as a result of external triggering. In order to clarify this question an analysis of the locations of the embedded young stellar objects (YSOs) in tlie dark clouds in the Gum-Vela region was undertaken. Since these embedded YSOs are obscured in tlie visible region by dust in the molecular clouds, the far-infrared point sources from tlie Infra-Red Astronomical Satellite catalogue were used to identify them. This study has clearly shown that the YSOs have a stastically significant tendency to fall on the sides of dark clouds facing the morphological center rather than the far sides.

From the above analysis we come to the following conclusions:

1. The rough agreement between tlie *expansion age* and the *tail-stretching* age suggests a common origin for the expansion and the formation of tlie tails. The presence of young stars of comparable ages in the heads of some of the globules suggests that tlie processes responsible for the expansion may have also triggered star formation in them.

2. The radiation pressure from the hot stars in tlie central region or the stellar winds from them cannot account for the momentum of tlie expanding globules. It is more likely that the *rocket effect* arising out of the heating and the consequent anisotropic ablation of tlie globules can supply the necessary momentum.

All the above conclusions can be reconciled easily if one could argue tliat they are causally connected and have a common origin. The main apparent obstacle to such a unified picture for the system of CGs in tlie Gum Nebula is tliat although there appears to be a morphological center there arc no identifiable objects, say, massive stars, *presently* located at or near tlie morphological center. However, the observed large proper motion of tlie massive star ζ Puppis holds an important clue, leading to tlie following scenario: It is an extraordinary fact that ζ Puppis has a large proper motion ~ 75 kms^{-1}, and its trajectory when extrapolated backwards passes close to the morphological center of the system of CGs. It lias been known for a long time that large space velocities of massive stars can only be understood in terms of the disruption of a massive binary system when one of tlie stars explodes as a supernova. If the supernova explosion is spherically symmetric then the binary will disrupt due to a sudden mass loss only if the mass ejected exceeds half tlie total mass of the binary system. Since the estimated mass of ζ Puppis is $\sim 40M_{\odot}$, it follows that its former companion must have been even more massive than this. If one accepts this picture then it follows that till roughly half a million years ago there must have been a massive binary system (ζ Puppis and its companion) near the center of the system of CGs. The combined effect of the ultra-violet radiation and the stellar wind from this binary as well as from other stars in tlie neighbourhood, must have resulted in much of the molecular material in the vicinity being blown away except the numerous regions of enhanced density (*condensations*) in tlie original molecular cloud. Continued effect of the radiation and stellar winds resulted in these condensations being set in motion, as well as developing cometary tails. Roughly half a million years ago the companion ζ Puppis exploded as a supernova propelling the latter towards its present location.