

**Detection of Complex Molecules from Millimeter Wavelength
Spectra Radiating from Interstellar Medium and Planetary
Objects**

Thesis

submitted to the Vidyasagar University

for the award of the degree of

DOCTOR OF PHILOSOPHY (SCIENCE)

by

Arijit Manna

(Reg. No.- 954/Ph.D. (Sc) w.e.f. 09.12.2022)

Under the guidance of

Dr. Sabyasachi Pal

Midnapore City College

Midnapore-721129, India

2026

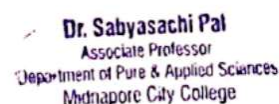
Certificate of Supervisor

This is to certify that the thesis titled "**Detection of Complex Molecules From Millimeter Wave-length Spectra Radiating From Interstellar Medium and Planetary Objects**", submitted by **Mr. Arijit Manna** to Vidyasagar University, Midnapore, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work conducted by him under my supervision and guidance. The contents of this thesis, in full or in part, have not been submitted to any other institution or university for the award of any degree or diploma. All comments and suggestions provided by the examiner have been duly incorporated in the revised version of the thesis.

I also declare that this thesis is written based on published works of Arijit Manna.



Dr. Sabyasachi Pal
Associate Professor & HOD
Department of Pure & Applied Sciences
Midnapore City College
Midnapore-721129
West Bengal, India


Dr. Sabyasachi Pal
Associate Professor
Department of Pure & Applied Sciences
Midnapore City College



Vidyasagar University

Plagiarism Testing Report

Name of Research Scholar: *Arijit Manna*

Title of the thesis: *Detection of Complex Molecules from Millimeter Wavelength Spectra Radiating from Interstellar Medium and Planetary Objects*

Name of Supervisors: *Dr. Sabyasachi Pal*

Department/Research Centre Name: *Biodiversity and Environmental Studies*

Institute Name: *Midnapore City College*

This is the report that the above thesis was scanned for similarity detection excluding bibliography and references. Result of testing report is given below:

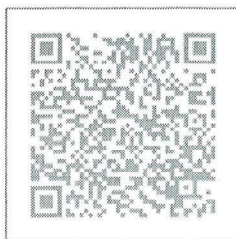
Software used: *DrillBit*

Similarity Indexed: *6 %*

The similarity index is within the accepted range.

Date: *17 February 2025*

Place: *Midnapore*



[Signature]
Director, IQAC

Vidyasagar University

Director
Internal Quality Assurance Cell
Vidyasagar University
Midnapore-721102

[Signature]
Registrar

Vidyasagar University

Registrar
VIDYASAGAR UNIVERSITY
Midnapore-721102

Abstract

Studying complex organic molecules in the interstellar medium (ISM) and planetary atmospheres is crucial for understanding their chemical compositions and complex biochemistry. The high- and low-mass star-forming regions, molecular clouds, and protoplanetary disks are ideal targets for observing complex molecular lines, as various molecules are formed and destroyed in these regions through gas-phase and grain-surface chemical reactions. In this thesis, we present molecular line observations towards hot molecular cores and hot corinos using the high-resolution Atacama Large Millimeter/Submillimeter Array (ALMA). Complex molecular lines in planetary atmospheres and cometary objects were also investigated. Several complex organic molecules were detected, including the possible precursors of the simplest amino acid, glycine ($\text{NH}_2\text{CH}_2\text{COOH}$). We also successfully detected various nitrogen (N)-, oxygen (O)-, and thiol (SH)-bearing molecules in hot molecular cores and hot corinos. After detection, the column density and excitation temperature of these molecules were estimated using the local thermodynamic equilibrium (LTE) and rotational diagram models. The LTE assumption is valid in hot cores and corinos because the gas and kinetic temperatures are nearly equal. Following the column density estimation, we derived the fractional abundances of the detected molecules with respect to molecular hydrogen (H_2). The detection of complex prebiotic molecules such as methylene imine (CH_2NH), methylamine (CH_3NH_2), cyanamide (NH_2CN), and aminoacetonitrile ($\text{NH}_2\text{CH}_2\text{CN}$), potential $\text{NH}_2\text{CH}_2\text{COOH}$ precursors, provides insight into how complex molecules create biological environments through various chemical reactions. To understand the formation mechanisms of the detected complex

organic molecules, we employed two-phase warm-up chemical modelling at different timescales using gas-grain chemical codes UCLCHEM and GGCHEMPY. Additionally, the rotational emission line of hydrogen cyanide (HCN) was detected in the atmosphere of Saturn. To derive the abundance of HCN from the atmosphere of Saturn, a planetary spectrum generator (PSG) radiative transfer model with different atmospheric layers was used. Furthermore, we detected evidence of atomic hydrogen (HI) from the comet C/2020 F3 (NEOWISE) using the Giant Metrewave Radio Telescope (GMRT). This study opens new avenues for understanding prebiotic chemistry in the universe. The detection of chemically related complex organic and prebiotic molecules in both interstellar hot cores and Solar System bodies such as comets suggests that common grain-surface chemical pathways operating on icy dust mantles may be universal, bridging the chemistry of star-forming regions and planetary systems.

Declaration of the Candidate

I hereby declare that the thesis entitled "**Detection of Complex Molecules From Millimeter Wavelength Spectra Radiating From Interstellar Medium and Planetary Objects**" is the original work carried out by me under the supervision of Dr. Sabyasachi Pal, Associate Professor, Department of Pure and Applied Sciences, Midnapore City College, Midnapore, West Bengal. I further declare that this work has not been previously submitted, partly or fully, for any other degree at this university or any other institution. I hereby declare that the revised version of the thesis has been prepared in accordance with, and duly incorporates, all the comments and suggestions provided by the examiner.

I also declare that this thesis is written based on my published works.

Arijit Manna

(Arijit Manna)

Research Scholar
Department of Pure & Applied Sciences
Midnapore City College
Midnapore-721129
West Bengal, India

Acknowledgements

I would like to express my sincere gratitude to Dr. Sabyasachi Pal for his inspiring leadership, enthusiastic encouragement, and continuous guidance throughout my PhD journey. His vast knowledge of various topics, including astrochemistry, motivated me to achieve my goals. Working under his supervision has been a thrilling and enriching experience that will undoubtedly shape my future career and life path. I extend my thanks to Prof. Pradip Ghosh, honourable director of Midnapore City College.

I am deeply grateful to my parents, Sri Dibakar Manna and Smt Bula Manna, for their blessings and unwavering support. I would like to thank Akash Maity, Ishan Kanrar, and Supriyo Ghorai for their constant support and encouragement. I am also indebted to my supervisor, Dr. Sabyasachi Pal, for his help during challenging times in my life. I would also like to thank my uncle Gautam Bodak for his continued motivation during my entire research journey. I would like to acknowledge my fiancée, Sheuli Chowdhury, for her unwavering support and encouragement. Finally, I would like to thank my collaborators, Dr. Serena Viti (Leiden Observatory), Dr. Tapas Baug (S.N. Bose National Centre for Basic Sciences), and Dr. Somnath Dutta (Academia Sinica Institute of Astronomy and Astrophysics), for the opportunity to learn from them, particularly in the field of astrochemistry and star-formation regions.

(Arijit Manna)