EVGENI KHARADZE GEORGIAN NATIONAL ASTROPHYSICAL OBSERVATORY

საჯარო სამართლის იურიდიული პირი
საქართველოს ევგენი ხარაძის ეროვნული ასტროფიზიკური ობსერვატორია

LEGAL ENTITY OF PUBLIC LAW
EVGENI KHARADZE GEORGIAN NATIONAL ASTROPHYSICAL OBSERVATORY

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13/02/2025

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To: **Dr. Tigran Yu. Magakian,**
Specialized Council in V. Ambartsumian Byurakan Astrophysical Observatory (BAO)

(e-mail: 048@hesc.am)

dear Tigran,

On February 12, 2025, the Scientific Council of the LEPL - Evgeni Kharadze Georgian National Astrophysical Observatory (GNAO) discussed Anait Samsonyan's thesis, "Investigation of Dusty Starburst Galaxies and Active Galactic Nuclei Through the Infrared [CII] 158 µm Emission Line," at their meeting. The thesis was submitted to the Council of the Byurakan Astrophysical Observatory (BAO) of the NAS RA for the academic degree of candidate in physical and mathematical sciences.

The electronic version of GNAO's Review as a Leading Organization (3 pages) is attached, while the original review was mailed.

Sincerely,

Revaz Chanishvili
Director

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Review

of the leading organization on the thesis of Anahit Samsonyan "Investigation of the dusty Starburst galaxies and Active Galactic Nuclei through the infrared [CII] 158 μm emission line", submitted for the degree of Doctor of Philosophy in specialization 01.03.02 -"Astrophysics and Radioastronomy".

Our understanding of the galaxy formation process can be facilitated by discovering of the extragalactic sources obscured by dust and tracing these sources till their earliest cosmological epochs. The extreme luminosities of dusty, local sources were originally revealed by observing the ultraluminous infrared galaxies (ULIRGs), the major feature of which arises from infrared emission by dust often obscures the primary optical sources. The importance of such galaxies was demonstrated by the different simulations demonstrating that the infrared dust emission from galaxies dominates the cosmic background luminosity.

In order to discover and understand the nature of dusty galaxies at even higher redshifts than the distant obscured galaxies (DOGs) known so far, the atomic line emission of [CII] 158 μm (the strongest far-infrared line) is the most important spectroscopic feature. Consequently, this line is of the key importance for redshift determinations and source diagnostics using submillimeter and millimeter spectroscopic observations. To date, [CII] has been detected at the redshifts higher than 8 and demonstrated to be strong in the starburst galaxies situated at $1 < z < 2.5$. The line [CII] can serve as a diagnostic for the star formation process, since it is primarily associated with the photodissociation region (PDR) which, in turn, is related to starbursts (SBs).

In a number of the high-redshift sources (especially, in DOGs), the [CII] feature is the only observable diagnostics for the atomic emission lines. Consequently, it's crucial to optimize a study of this line for making clear the intrinsic source properties.

A great amount of diagnostical information related to the observable differences between dusty, obscured sources powered by active galactic nuclei (AGNs) and those powered by rapid star formation ("starbursts") has been collected via the mid-infrared spectroscopy of the Infrared Spectrograph (IRS) on the Spitzer Space Telescope. Different classifications of the AGN and starburst sources have been developed based on the both the strength of polycyclic aromatic hydrocarbon (PAH) features in low-resolution spectra and various emission line ratios in high-resolution spectra.

These findings demonstrate the crucial role of far-infrared diagnostics, particularly, that of the [CII] 158 μm emission line, in revealing the complexities of galaxy evolution. The integration of mid-infrared spectroscopic tools, submillimeter observations, and modern classifications have significantly advanced the abilities to discern between the AGN-driven and starburst-driven processes in the dusty, high-redshift galaxies. By adopting the [CII] line as a robust tracer for the star formation and interstellar medium properties, this research provides us with a foundation for probing the earliest stages of galaxy formation, bridging observational gaps, and refining models of the cosmic evolution. The capability for studying both the physical conditions and kinematics of these distant galaxies sets a path for the future explorations, further enabling the discovery of hidden populations of galaxies in the early universe.

The thesis of A. Samsonyan's is devoted to the study of the AGN and starburst galaxies, observed with Spitzer Space Telescope and Herschel Space Observatory. It is based on four refereed scientific papers, which were published in prestigious scientific journals.

The thesis contains 6 chapters, including INTRODUCTION and CONCLUSIONS. In addition, there are separate sections for ACKNOWLEDGEMENTS and REFERENCES. It totally amounts to 123 pages.

The INTRODUCTION (**Chapter 1**) highlights a crucial role of the infrared astronomy, particularly, that of the [CII] 158 μm emission line, in studying the active galaxies and dusty, high-redshift sources; the importance of the line [CII]m as a diagnostic tool for distinguishing between the AGN- and starburst-driven processes, tracing star formation, and unraveling the complexities of galaxy evolution, with implications for our understanding of the earliest cosmological stages.

Chapter 2 presents the Herschel Space Observatory data related to the [CII] measurements in 112 galaxies, revealing a strong correlation between the [CII]-luminosity and PAH emission, validating [CII] as a reliable tracer of star formation in photodissociation regions. It introduces a calibration method for the star formation rates (SFR), based on [CII] luminosity and analyzes the "[CII] deficit" in the luminous AGNs, attributing it to the AGN dominance reducing [CII] relative to the total infrared luminosity.

Chapter 3 investigates the relationship between the [CII] and mid-infrared emission lines, such as neon lines, to refine SFR diagnostics, utilizing data from Spitzer IRS and Herschel PACS. The key findings include the calibration of the SFR by using the [CII] and [NeII]/[NeIII] fluxes, confirming the [CII] flux to be a reliable measure of the starburst activity (independently of theclassification), and highlighting its complementarity with PAH and neon emissions in disentangling the starburst and AGN contributions.

In **Chapter 4,** the analysis of [CII] and neon ([NeII], [NeIII]) emission line profiles are presented to explore the kinematic properties of gas in AGN- and starburst-dominated galaxies, utilizing high-resolution spectra from Herschel PACS and Spitzer IRS. The results show that (a) the [CII] and [NeII] line widths remain consistent across the different classifications, while the [NeIII] line widths exhibit increasing trends from the starbursts to AGNs; (b) [CII] and [NeII] scale together and represent the starburst component of the galaxy and are a key diagnostic of star formation in diverse galactic environments, while the [NeIII] arises both from AGN ionization and SB ionization.

Chapter 5 analyzes the [CII] line width in 379 galaxies, classifying the line profiles as Gaussian, flattened, or asymmetric to explore their connection to the gas dynamics and galaxy evolution. The emission line widths are compared to the [CII] luminosities (which scales primarily with the photodissociation regions, surrounding the starbursts and, therefore, scales with the gas mass connected to star formation), to the near-infrared 1.6 μm luminosities (which scales with the total luminosity of the evolved stars) and to the infrared 22 μm luminosities (which scales with the total luminosity of younger, hotter stars that are heating the dust) to conclude whether any luminosity accurately relates to the velocity dispersion. While variations in the [CII] line shapes could reveal a turbulence, ionization, and potential differences between the AGN-driven outflows and starburst winds, the presented findings does not show any consistent relationship between the line widths and galaxy luminosities, suggesting that line widths are influenced by the mechanisms beyond the gravitational effects of the evolved stars.

The "CONCLUSIONS" chapter (**Chapter 6**) summarizes the thesis by highlighting the [CII] 158 μm line as a critical diagnostic tool for investigating the dusty starburst galaxies and AGNs, emphasizing its role in tracing star formation, gas dynamics, and energy sources shaping the galaxy evolution.

The next section is "**ACKNOWLEDGEMENTS**, followed by the "**References**" section, which contains 139 citations in total.

The significance of this thesis is represented in the ability to address the key scientific challenges in the discovery and study of dusty galaxies at high redshifts, providing thus the different insights into the earliest cosmological epochs. These findings, , based on the modern observational techniques and advanced data analysis methods, are undeniably robust and highly relevant. The thesis is well-illustrated, effectively supporting the presented results.

Note also some Minor drawbacks as follows:

● Each paragraph should start with an indent.

● Some sentences are exceedingly long and difficult to read.

● Some parts of the manuscript require a minor grammatical improvement (e.g., articles are missing or incorrectly used).

● Bullets could be used in those parts which presents a list (e.g., description of the AGN structure, AGN classes, sources of the molecular or atomic infrared lines etc.)

However, the aforementioned drawbacks do not diminish the overall quality of the work. The author's publications are highly relevant to the research topic and strongly aligned with the thesis. Furthermore, the thesis is built upon the original findings that have been published in the top-ranked international scientific journals, underscoring its scientific significance and credibility. The results of the thesis can be utilized by scientific organizations and observatories worldwide conducting similar research.

The thesis represents a highly-qualified scientific work, presenting the results achieved by the author within the collaboration with her scientific colleagues. It fully meets the requirements for a Doctor of Philosophy degree in physical and mathematical sciences by Supreme Certifying Committee of the Republic of Armenia. The author, A. Samsonyan, unquestionably merits the award of the PhD degree in the specialization 01.03.02 – Astrophysics and Radioastronomy.

Leading Organization: LEPL - Evgeni Kharadze Georgian National Astrophysical Observatory:

George Chagelishvili

Chairman of the Academic Council, Academician

Revaz Chanishvili
Director