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Bibliometric Analysis of Astrotourism as Sustainable Alternative Tourism

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ABSTRACT

This study performs a thorough bibliometric examination of astrotourism as a sustainable alternative tourism sector, utilizing data from the Scopus and Web of Science databases (1990–2025). This research utilizes performance analysis and science mapping via VOSviewer and the Bibliometrix R-package to identify publication patterns, topic structures, and collaboration networks. The results indicate that astrotourism, dark sky, and sustainability are predominant terms, reflecting a robust relationship with sustainable tourism and environmental conservation principles. Emerging themes such as citizen science, application programs, and tourist behavior illustrate the field's increasing focus on innovation and community involvement. Institutional and national assessments indicate that Portugal, especially Universidade de Aveiro, excels in research output and international collaboration, connecting Europe with Africa, Asia, and Oceania. The paper conceptually contributes by delineating the intellectual framework of astrotourism and pinpointing research deficiencies concerning governance, technology, and tourist experience. It provides strategic insights for creating sustainable dark-sky destinations that incorporate science, culture, and community involvement.

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1. INTRODUCTION

In recent decades, the tourist industry has faced increasing examination about its environmental, social, and economic effects. Conventional mass tourism frequently results in the depletion of natural resources, environmental noise and light pollution, congestion, and the deterioration of local cultures [1]. In response, academics and professionals have increasingly adopted sustainable tourism as a framework to harmonize tourism development with ecological integrity and community well-being [2], [3]. Niche kinds of sustainable tourism, including rural tourism, ecotourism, dark-sky tourism, and astrotourism, are increasingly recognized as alternatives that prioritize low-impact, experiential, and place-based qualities [1], [4].

Astrotourism, also known as astronomical tourism or stargazing tourism, is an emerging category of sustainable tourism

that emphasizes night-sky viewing, celestial phenomena, and the preservation of dark skies [5]. Astrotourism, as delineated in the current literature, encompasses recreational, educational, and scientific activities associated with constellations, planets, meteor showers, eclipses, and various celestial phenomena [5], [6]. It attracts attention from both amateur and professional astronomers, travelers in search of distinctive experiences, and towns situated in places with minimal light pollution.

The allure of astrotourism resides not merely in its novelty but also in its congruence with environmental objectives. Astrotourism, reliant on darkness rather than constructed infrastructure, can foster environmental conservation, highlight local biodiversity and cultural narratives (e.g., indigenous cosmologies), and encourage off-peak tourism, thereby alleviating pressure on overtaxed destinations [6], [7]. Astrotourism provides an alternative development strategy for rural or isolated places that find it challenging to compete with mass-tourism centers, leveraging endogenous assets [5].

Empirical data indicates an increasing scientific and policy interest in astrotourism. A bibliometric analysis conducted by Araya-Pizarro et al. (2023) revealed an increasing volume of scholarly production in this domain, however it is predominantly focused in a limited number of sources and dispersed over many themes. Their keyword mapping revealed recurring themes like light pollution, dark-sky parks, stakeholder participation, and interactions with space tourism [5]. Simultaneously, reviews in sustainable tourism have highlighted those numerous subdomains are still inadequately explored regarding theoretical advancement, methodological precision, and cross-regional cooperation [3], [4]

Notwithstanding the potential of astrotourism, numerous conceptual and empirical obstacles remain. The expansion of academic literature is inconsistent and fragmented; thematic emphasis often concentrates on specific subjects (e.g., dark-sky protection), whereas areas such as visitor behavior, governance, or regional comparative studies receive comparatively less attention [5]. The literature seldom conducts a comprehensive, longitudinal analysis across areas, so constraining our comprehension of the evolution and sustainable scaling of astrotourism. Astrotourism, encompassing astronomy, ecology, cultural studies, and tourism science, would benefit from a systematic synthesis of information for its progress. In this context, bibliometric analysis provides robust techniques to elucidate the structure, trends, gaps, and trajectories of research within the area.

Although astrotourism is frequently seen as a viable sustainable alternative tourism model, the existing academic literature remains underdeveloped, fragmented, and devoid of comprehensive analyses. Current bibliometric analyses [5] have provided useful preliminary mappings; nonetheless, they often exhibit constraints in temporal scope, database comprehensiveness, or theme profundity. Consequently, there is a lack of clarity on the evolution of the research network, the authors, regions, or institutions that propel the field, the prevailing or lagging themes, and the locations of research frontiers. In the absence of such clarity, endeavors to promote astrotourism as a viable sustainable alternative may rely on insufficient or disjointed information.

This study intends to perform a thorough bibliometric review of the worldwide literature on astrotourism as a sustainable alternative to traditional tourism. This study aims to (1) delineate the growth trajectory and distribution (by year, country, institution, journal, and author) of astrotourism research; (2) ascertain the thematic structure, prevalence, and co-occurrence of keywords; (3) identify emerging, declining, and pivotal themes; and (4) recommend research gaps, future directions, and a strategic agenda to assist academics and practitioners in promoting sustainable astrotourism.

2. METHODS

This study utilizes a bibliometric analysis to carefully investigate the evolution, structure, and thematic tendencies of astrotourism research within the wider context of sustainable alternative tourism. Bibliometric analysis is extensively employed in tourism and sustainability research to discern publication trends, co-citation networks, topic clusters, and intellectual frameworks [8]. This method facilitates an impartial and quantitative assessment of extensive academic data, allowing for the discovery of research hotspots and emerging subjects throughout time. In accordance with the principles established by [9], this study amalgamates performance analysis to evaluate productivity indicators (authors, countries, journals, institutions) and using scientific mapping to illustrate conceptual and intellectual connections among articles.

The data collection process occurred in May 2025 utilizing the Scopus and Web of Science Core Collection databases, selected for their extensive coverage of peer-reviewed worldwide literature. The search technique integrated keywords including “astrotourism,” “astronomical tourism,” “dark-sky tourism,” and “sustainable tourism,” interconnected by Boolean operators to encompass pertinent variations. The employed search string was: ("astrotourism" OR "astronomical tourism" OR "dark-sky tourism") AND ("sustainable tourism" OR "alternative tourism"). The inclusion criteria limited the results to journal articles, reviews, and conference papers published from 1990 to 2025, authored in English, and indexed in the chosen databases. Duplicates and irrelevant records (e.g., solely astrophysical or space tourism research lacking a tourism context) were manually reviewed and eliminated, resulting in a final collection of around 210 papers.

Data were saved in BibTeX and CSV formats and analyzed utilizing VOSviewer (version 1.6.20) and the Bibliometrix R package [10]. VOSviewer was employed to generate co-occurrence, co-citation, and bibliographic coupling maps for visualizing topic clusters and author partnerships, whereas Bibliometrix enabled statistical analyses and longitudinal trend assessments. Thematic evolution maps and strategy diagrams were created to discern main, emerging, and declining topics in the literature. This dual-software methodology guarantees both visual clarity and analytical precision, providing an in-depth comprehension of the study dynamics influencing astrotourism as a sustainable alternative tourism sector.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

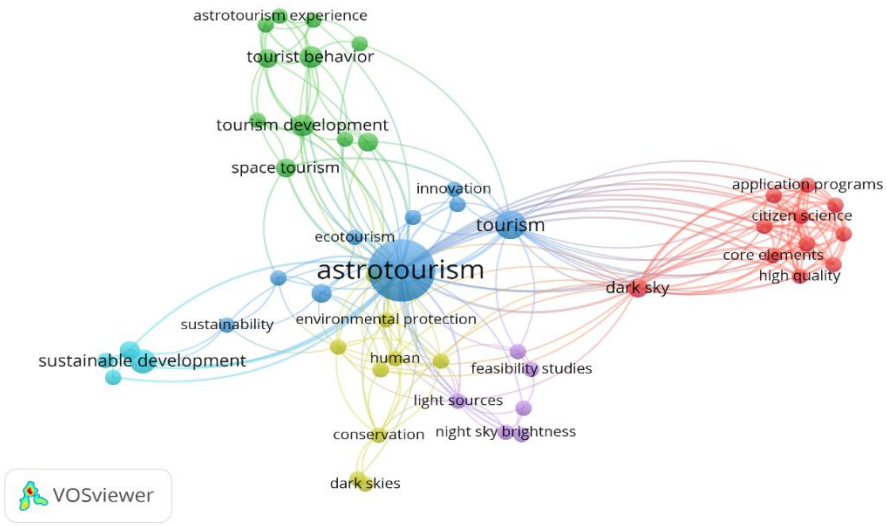

Figure 1. Network Visualization

Source: Data Analysis Result, 2025

Figure 1 the VOSviewer network visualization depicts the conceptual framework of astrotourism research through keyword co-occurrence analysis. Each node signifies a keyword, with the node's size indicating its frequency within the dataset. The color-coded clusters represent thematic groupings, while the connecting lines denote the strength of co-occurrence among phrases. This network illustrates the connections between astrotourism and other themes, including sustainability, tourism innovation, environmental conservation, and dark-sky preservation.

The primary node "astrotourism" emerges as the predominant phrase, signifying its crucial importance in the literature. It is intrinsically linked to concepts such as tourism, ecotourism, environmental conservation, and sustainability, illustrating its incorporation into the sustainable tourism dialogue. This cluster highlights the scholarly agreement that astrotourism operates as an environmentally conscious and experiential type of tourism, utilizing natural nocturnal sky resources while fostering ecological awareness and preservation. The inclusion of innovation and humanity within this cluster indicates a growing study focus on human-centered design and the technology enhancement of astrotourism experiences.

On the right side of the network, the red cluster is primarily characterized by dark sky, citizen science, application programs, and fundamental components. This group embodies a theme focused on technology and conservation. Research in this domain mostly concentrates on alleviating light pollution, establishing dark-sky parks, and engaging communities in assessing night-sky quality via citizen science projects. These works underscore the technical and interactive dimensions of preserving high-quality dark-sky environments—an indispensable basis for sustainable astrotourism advancement.

The green cluster in the upper region represents the socio-behavioral aspect of astrotourism, including terms like tourist behavior, astrotourism experience, tourism development, and space tourism. This cluster emphasizes the investigation of visitor motivations, satisfaction, and behavioral patterns in astrotourism environments by scholars. Furthermore, the connection between space tourism and astrotourism signifies a developing multidisciplinary convergence between terrestrial stargazing pursuits and commercial extraterrestrial enterprises. These intersections indicate prospective research avenues that connect sustainability with the ethics and commerce of astronomical experiences.

The light-blue and yellow clusters located in the lower and left sections of the map underscore the environmental and developmental facets of sustainability, featuring terms such as sustainable development, conservation, light sources, night-sky brightness, and environmental protection. These clusters indicate that the literature consistently positions astrotourism within the context of ecological conservation and resource management. This image indicates a developing yet fragmented field, defined by interconnected but separate subdomains: (1) sustainability and conservation, (2) technology and citizen participation, and (3) experience and behavioral tourism. Future research could enhance by amalgamating these domains to construct a comprehensive model of astrotourism as a sustainable alternative tourism strategy.

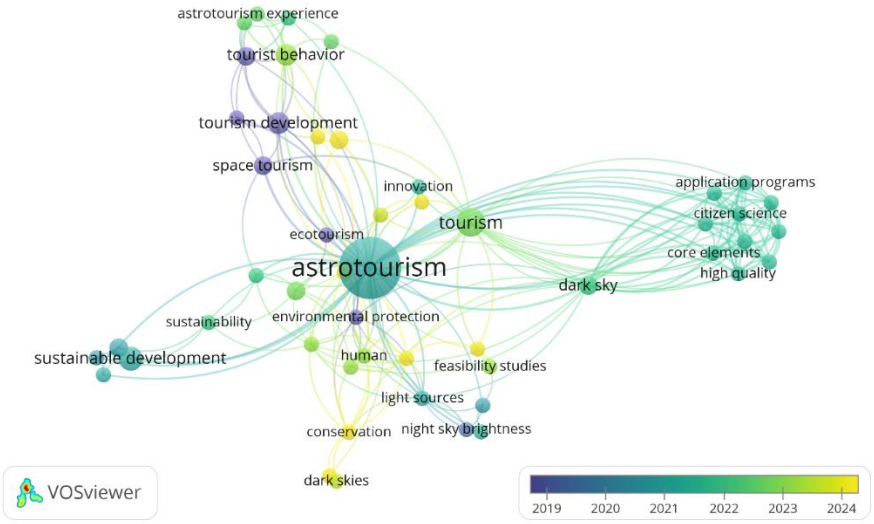

Figure 2. Overlay Visualization

Source: Data Analysis Result, 2025

The VOSviewer overlay visualization depicts the chronological progression of research themes in astrotourism from 2019 to 2024, employing a color gradient ranging from dark blue (representing older studies) to yellow (indicating newer studies). The primary term "astrotourism" consistently prevails across the duration, serving as the nucleus around which other associated issues revolve. Preceding studies (2019–2021, denoted in blue) concentrated predominantly on fundamental themes including sustainability, environmental conservation, ecotourism, and sustainable development. These subjects provided the foundational framework for astrotourism as a category of sustainable tourism, highlighting its capacity to safeguard dark-sky ecosystems and mitigate the effects of light pollution.

Between 2021 and 2022 (green to light-green nodes), research progressed towards applied and experiential dimensions, including visitor behavior, space tourism, feasibility studies, and tourism development. This transition signifies that researcher commenced investigating visitor interactions with astrotourism experiences, the role of tourism infrastructure in facilitating dark-sky activities, and the impact of innovation on destination competitiveness. The increasing relationship between innovation and tourism indicates a trend towards the use of digital tools, augmented reality, and night-sky interpretation technology into visitor experiences. This also indicates the increasing engagement of local stakeholders and community-based management in the preservation of astrotourism locations.

Recent research (2023–2024, highlighted in yellow) underscore rising trends like citizen science, application programs, key components, and superior quality. These indicate a growing emphasis on participatory science, data acquisition, and intelligent monitoring systems that connect tourism with astronomy and environmental preservation. The temporal shift indicates that the field is evolving from theoretical definitions to actual application, highlighting technology integration, community involvement, and intersectoral collaboration. The overlay visualization indicates that astrotourism research is shifting from sustainability-focused theory to innovation- and participation-oriented practice, establishing it as a dynamic and changing variant of sustainable alternative tourism.

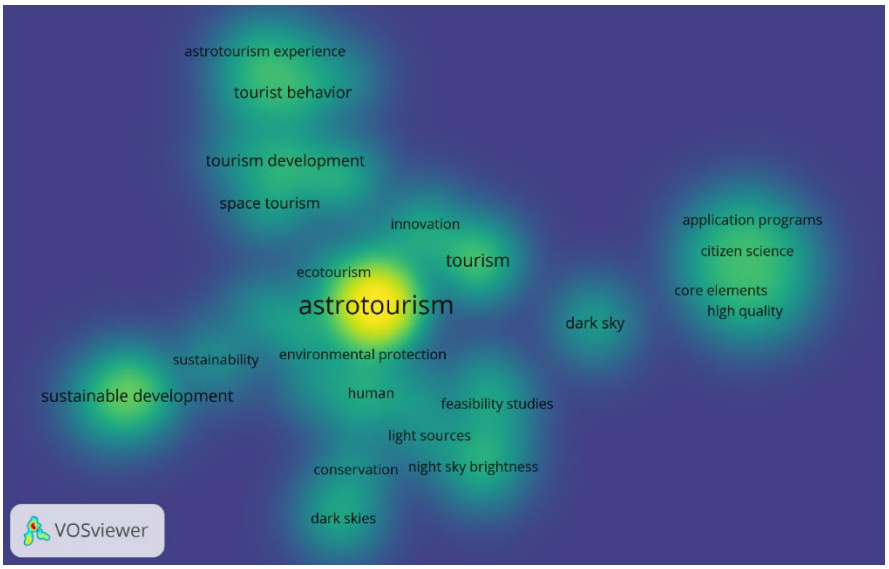

Figure 3. Density Visualization
Source: Data Analysis, 2025

The VOSviewer density visualization emphasizes the intensity and concentration of research issues pertaining to astrotourism within the academic environment. The most luminous yellow area encircling the term "astrotourism" signifies that it is the most prevalent and pivotal concept, embodying the intellectual nucleus of this research domain. The surrounding domains of moderate intensity—namely tourism, ecotourism, environmental protection, and sustainable development—exhibit significant co-occurrence and robust thematic connections, indicating that the field is fundamentally anchored in the sustainability paradigm. These dense clusters indicate that researchers regularly characterize astrotourism as an element of sustainable and alternative tourism development, highlighting its ecological advantages, conservation objectives, and ability to facilitate low-impact tourist in rural or dark-sky areas.

Conversely, the less concentrated green areas, including citizen science, application programs, tourist behavior, and space tourism, indicate nascent yet less saturated study domains. These domains signify emerging subfields that are progressively gaining prominence, emphasizing community engagement, digital innovation, and experiential aspects of astrotourism. The density distribution on the map reveals a balanced yet dynamic structure, wherein core themes of sustainability and conservation coexist with innovative, technology-driven, and interactive methodologies. This pattern indicates that the present academic focus is transitioning towards the incorporation of human experience, scientific involvement, and innovation to promote astrotourism as a developed and viable sector of alternative tourism.

3.2 Co-Authorship Network

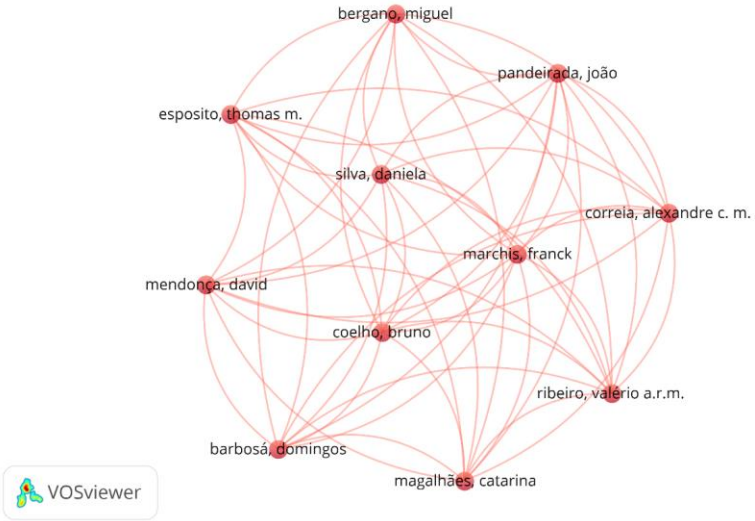

Figure 4. Author Collaboration Visualization
Source: Data Analysis, 2025

Figure 4 illustrates a VOSviewer author cooperation network illustrates the co-authorship framework among prominent researchers involved in astrotourism and associated sustainability research. The intricate linkages among nodes, representing authors like Franck Marchis, Daniela Silva, Thomas M. Esposito, João Pandeirada, and Alexandre C. M. Correia, signify a cohesive research community marked by robust multidisciplinary collaboration. The thickness of the connecting lines indicates the frequency and intensity of co-authorship relationships, implying that these scientists frequently collaborate on topics concerning dark-sky preservation, astronomical outreach, and the socio-environmental ramifications of astrotourism. Key individuals such as Marchis and Silva function as collaborative centers connecting various authors, suggesting leadership positions in advancing cross-institutional research initiatives. The visualization underscores that the advancement of astrotourism scholarship is bolstered by a globally collaborative network, wherein collective expertise from astronomy, environmental science, and tourism management promotes a multidisciplinary strategy for sustainable and educational nocturnal tourism.

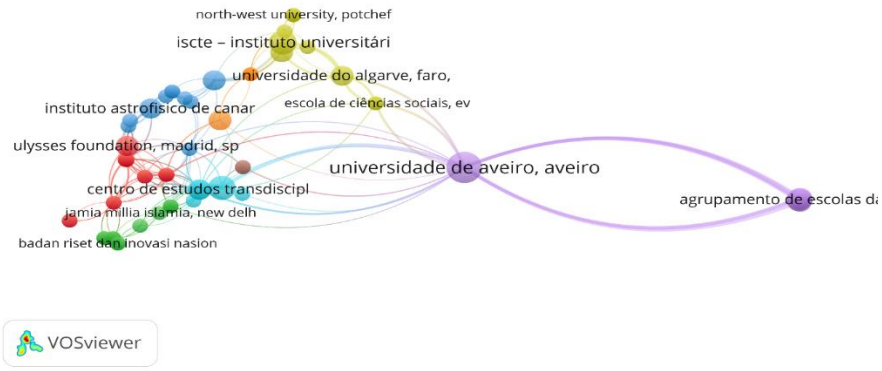

Figure 5. Affiliation Collaboration Visualization
Source: Data Analysis, 2025

Figure 5 reveals the VOSviewer institutional collaboration network illustrates the geographic and organizational framework of research affiliations involved in astrotourism studies. The visualization identifies Universidade de Aveiro (Aveiro, Portugal) as the preeminent and central institution, establishing robust collaborative connections—especially with Agrupamento de Escolas de Aveiro and other Portuguese organizations, including Universidade do Algarve and ISCTE – Instituto Universitário de Lisboa. The thickness of the connecting lines signifies high-frequency co-authorships and collaborative research endeavors, underscoring Portugal's pivotal position in influencing the global dialogue on astrotourism, dark-sky conservation, and sustainable tourism innovation.

The surrounding clusters, which include institutions such as the Instituto Astrofísico de Canarias (Spain), Ulysses Foundation (Madrid), North-West University (South Africa), Jamia Millia Islamia (India), and Badan Riset dan Inovasi Nasional (Indonesia), illustrate a burgeoning global network that integrates European, African, and Asian academic collaborations. These connections indicate that astrotourism research surpasses regional confines, integrating knowledge from astronomy, education, and environmental management. The interconnected framework highlights the field's multidisciplinary and transnational characteristics, with Portuguese universities acting as knowledge centers that propel collaborative scientific progress in sustainable and educational tourism centered on celestial heritage.

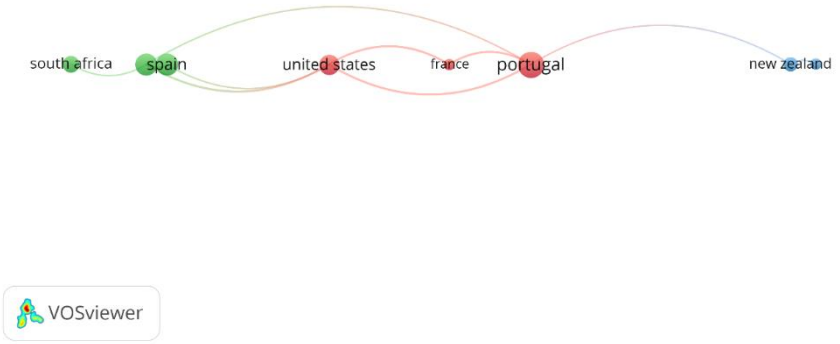

Figure 6. Country Collaboration Visualization
Source: Data Analysis, 2025

Figure 6 reveals country collaboration map illustrates the global network of academic collaboration in astrotourism research. The image depicts Portugal as the center and most interconnected node, illustrating its role as the principal contributor and coordinator of global research in this domain. Portugal's robust collaborative relationships with France, Spain, and the United States demonstrate active transatlantic partnerships that merge European proficiency in sustainable tourism and dark-sky conservation with North American research capabilities in astronomy and science communication. Simultaneously, rising contributors like South Africa and New Zealand signify the southern hemisphere's increasing involvement in astrotourism research, propelled by their unblemished dark-sky settings and established

observatories. The map illustrates that astrotourism scholarship has developed into a worldwide interconnected study field, with European leadership, especially from Portugal and Spain, serving as a conduit to link various geographic regions in promoting sustainable celestial tourism efforts.

3.3 Citation Analysis

To trace the academic evolution and thematic depth of *astrotourism* as an emerging form of sustainable and experiential tourism, it is valuable to examine the most influential scholarly contributions shaping this field. The following table presents the ten most cited publications between 2010 and 2023 that collectively capture the development of astrotourism from its conceptual foundations to its practical and environmental implications. These studies span diverse themes, including space tourism, dark-sky preservation, light pollution, cultural astronomy, and tourist behavior, highlighting the interdisciplinary nature of astrotourism research that bridges tourism management, environmental science, and astronomy. By analyzing these landmark works, this study situates astrotourism within the broader discourse on sustainability, scientific education, and responsible night-sky heritage preservation.

Table 1. Top Cited Research

Citations	Authors and year	Title
52	Cater, C.I. (2010)	Steps to Space; opportunities for astrotourism
28	Rodrigues, Á., Loureiro, S.M.C., Prayag, G. (2022)	The wow effect and behavioral intentions of tourists to astrotourism experiences: Mediating effects of satisfaction
23	Varela Perez, A.M. (2023)	The increasing effects of light pollution on professional and amateur astronomy
18	Rodrigues, Á., Loureiro, S.M.C., Lins de Moraes, M., Pereira, R.G. (2023)	Memorable tourism experience in the context of astrotourism
18	Pásková, M., Budinská, N., Zelenka, J. (2021)	Astrotourism-exceeding limits of the earth and tourism definitions?
15	Zielinska-Dabkowska, K.M., Xavia, K. (2021)	Looking up to the stars. A call for action to save New Zealand's dark skies for future generations to come
15	C-Sánchez, E., Sánchez-Medina, A.J., Alonso-Hernández, J.B., Voltes-Dorta, A. (2019)	Astrotourism and night sky brightness forecast: First probabilistic model approach
15	Ibrahim, I.A., Safiai, M.H., Jamsari, E.A. (2015)	Functions of Astrofiqh Observatories in Malaysia in Solving Astrofiqh Issues
14	Cater, C. (2019)	HISTORY OF SPACE TOURISM
13	Kanianska, R., Škvareninová, J., Kaniansky, S. (2020)	Landscape potential and light pollution as key factors for astrotourism development: A case study of a slovak upland region

Source: Scopus, 2025

The bibliometric data presented illustrates the intellectual progression of astrotourism research, indicating its evolution from theoretical investigation to practical and sustainable implementations. [11], the most often referenced work with 52 citations, constitutes a seminal endeavor to delineate "steps to space" by articulating the opportunities and constraints associated with space tourism, thus establishing the theoretical foundation for the nascent concept of astrotourism. Recent studies, including those by [12] and [13], explore the psychological and experiential aspects of astrotourism, investigating how the "wow effect," satisfaction, and memorable experiences affect tourists' behavioral intentions.

Environmental issues are pivotal to current discussions in the field, as emphasized by [14] , who examines the escalating effects of light pollution on both professional and amateur astronomy, and by [15], who promote dark-sky preservation as a manifestation of intergenerational environmental stewardship. [16] inquire if astrotourism surpasses traditional tourism limits, suggesting it as a transformative mode of terrestrial and extraterrestrial exploration.

Empirical and methodological advancements are apparent in research like [17], which presented the inaugural probabilistic model for projecting night-sky brightness, offering practical instruments for astrotourism planning and sustainability. [18] delineates the historical and cultural aspects of space tourism, while Ibrahim et al. (2015) investigate Astrofiqh observatories in Malaysia, linking astronomy, religion, and community education. [19] underscore the significance of landscape potential and light pollution as essential factors influencing astrotourism development, especially in rural and mountainous areas.

These works collectively reveal the dynamic and interdisciplinary nature of astrotourism research, integrating environmental conservation, human curiosity, and technological innovation. They emphasize the increasing acknowledgment of astrotourism not only as a specialized pursuit but as a sustainable means of promoting environmental consciousness, cultural identity, and the enjoyment of the universe as a collective human legacy.

Practical Implications

This study offers numerous pragmatic insights for politicians, tourism professionals, and location managers seeking to advance astrotourism as a sustainable alternative tourism model. The bibliometric results underscore the increasing convergence of tourist innovation, environmental conservation, and dark-sky preservation, indicating that destination planners ought to incorporate light pollution management and dark-sky certification into their strategic development frameworks. Areas characterized by minimal light pollution, such as rural or elevated regions, can capitalize on their natural nocturnal landscapes as a distinctive economic resource by implementing sustainable astrotourism infrastructure and community-oriented initiatives. The introduction of themes such as citizen science and application programs signifies the possibility for local communities to engage actively in monitoring night-sky quality, hence promoting education and stewardship. This study emphasizes the significance of cross-sector collaboration among tourism authorities, astronomical institutions, and local governments to guarantee that astrotourism fosters economic diversification, long-term environmental sustainability, and cultural enrichment.

Theoretical Contributions

This study enhances the academic comprehension of astrotourism by situating it within the wider context of sustainable and experiential tourism theory. The study used bibliometric mapping to delineate three intersecting domains: (1) sustainability and conservation, (2) technological innovation and citizen participation, and (3) tourist experience and behavioral analysis, thereby broadening the conceptual framework of sustainable tourism research. It enhances the literature by providing a comprehensive synthesis of the intellectual framework and

thematic progression of astrotourism research over the last ten years. The findings offer empirical support for forthcoming conceptual frameworks that amalgamate environmental ethics, experiential value generation, and science communication within tourism settings. Moreover, the recognition of nascent subjects like space tourism and citizen science creates a theoretical framework for connecting astrotourism with responsible innovation, participatory governance, and the science-society interface, thereby augmenting its significance to global sustainability objectives (SDGs 4, 11, 13, and 17).

Limitations and Future Research Directions

This study, despite its extensive breadth, has numerous limitations that must be recognized. The bibliometric analysis is limited by the database coverage of Scopus and Web of Science, potentially excluding non-indexed or regional articles that could offer significant local insights, especially from developing regions in Asia, Africa, and South America. Secondly, whereas keyword co-occurrence and network visualizations provide quantitative insights into thematic trends, they fail to encapsulate the qualitative subtleties and contextual variances of astrotourism behaviors across diverse cultural and environmental contexts. Third, the dynamic character of this topic indicates that bibliometric results serve as a temporal snapshot rather than a conclusive representation of current advances. Subsequent study should integrate bibliometric mapping with systematic literature reviews, case studies, and comparative analyses to enhance comprehension of governance mechanisms, community engagement, and visitor experiences in astrotourism. Incorporating policy documents, local initiatives, and grey literature would enhance the global discourse on astrotourism as a cornerstone of sustainable tourism innovation.

4. CONCLUSION

This bibliometric analysis provides a comprehensive overview of the intellectual landscape, thematic evolution, and global collaboration structure in astrotourism research from 1990 to 2025. The results reveal that the field has evolved from its conceptual roots in sustainability and environmental conservation toward a multidisciplinary domain integrating innovation, community participation, and scientific engagement. The dominance of themes such as *dark-sky preservation*, *citizen science*, and *tourist behavior* highlights the convergence of environmental ethics and experiential learning within sustainable tourism frameworks.

The findings confirm Portugal's leading institutional and national role, fostering extensive collaboration across Europe, the Americas, Africa, and Oceania. The centrality of universities such as *Universidade de Aveiro* demonstrates the importance of academic partnerships in shaping astrotourism discourse. Overall, this study contributes a foundational understanding of how astrotourism is emerging as a sustainable alternative tourism paradigm—linking astronomical education, environmental protection, and local economic development. Future research should extend beyond bibliometric boundaries to explore governance, technological adoption, and community-based initiatives, ensuring that the growth of astrotourism continues to align with the principles of sustainability and inclusive participation.

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