Scientific Writings from the Ancient and Medieval World

LEARNING WITH SPHERES

THE *GOLĀDHYĀYA* IN NITYĀNANDA'S *SARVASIDDHĀNTARĀJA*

Anuj Misra

ROUTLEDGE

Learning With Spheres

This book provides, for the very first time, a critical edition and an English translation (accompanied by critical notes and technical analyses) of the chapter on spheres (*golādhyāya*) from Nityānanda's *Sarvasiddhāntarāja*, a Sanskrit astronomical text written in seventeenth-century Mughal India.

Readers will learn how terrestrial and celestial phenomena were understood by early modern Sanskrit astronomers using spherical geometry. The technical discussions in this book, supported by the critically edited Sanskrit text and geometric diagrams, offer an opportunity for historians of the astral sciences to understand developments in astronomy in seventeenth-century Mughal India from a more nuanced perspective. These are supplemented through explorations of modernity, mathematics, and mythology and how they thrived within Sanskrit astronomical discourse at the courts of the Mughal emperors.

This book will be of interest to historians and philosophers of science, in particular those interested in the history of non-Western astral sciences. The book will be a valuable resource for scholars studying the general history of Sanskrit astronomy in the Indian subcontinent as well as those interested in the technical aspects of Sanskrit and Indo-Persian astronomy in Mughal India.

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Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2023
by Routledge
4 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
605 Third Avenue, New York, NY 10158

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-138-58357-3 (hbk)
ISBN: 978-1-032-31636-9 (pbk)
ISBN: 978-0-429-50668-0 (ebk)

DOI: 10.4324/9780429506680

Typeset in TeX-Gyre-Pagella
by codeMantra

**To those who taught me to think,
to those who sat with me thinking,
and to those who loved me as I thought.**

तं वन्दे परनिण्यदां कवितमं सिद्धान्तवादेषु य-
मानन्दस्थितिवर्तनं सुमुदितं नित्यं हि भाष्यं विना ।
साध्येयं ह्यपि वर्णनामिति मतिं मत्वा श्रयेत्कं पुन-
र्यत्नित्योर्मिरुदेत्यविज्ञमनसा भाष्ये ऽनुजे शाम्यतु ॥

taṃ vande paraniṇyadāṃ kavitamaṃ siddhāntavādeṣu yam-
ānandasthitivartanaṃ sumuditaṃ nityaṃ hi bhāṣyaṃ vinā |
sādhyeyaṃ hy api varṇanām iti matiṃ matvāśrayet kaṃ punar-
yatnityormir udety avijñamanasā bhāṣye 'nuje śāmyatu ||

I praise him, the giver of great mystery, who is the wisest among those who talk about the *siddhānta*s, [the one who remains] abiding in a state of bliss forever delighted without ever speaking. But who should one appeal to thinking that one might get an explanation? May this perpetual wave of despair that arises in an ignorant mind be quelled in a later commentary [that follows].

Contents

Figures

Tables

1 Introduction

The astral sciences were among the first organised systems of investigating the heavens in a long tradition of human inquiry about the natural world. The study of astral sciences grew out of the cradle of theology, mythology, and prophecy, and over the course of its history, it itself became the grounds where the methods of arithmetic, geometry, and abstraction thrived.[1] By medieval times, astronomers began determining the movements of the heavens with increasingly sophisticated numerical, geometrical, and graphical techniques. Their findings not only gave them insights into the inner workings of nature, but also invested them with the power to explore this knowledge for social benefit. Spherical geometry now explained the motions of celestial objects and catarchic astrology interpreted their destined impact. This meant that practising astronomers could accrue fame in their societies as scholars in service of imperial, noble, or papal courts.

For Sanskrit astronomers, the royal patronage of the Mughal courts (1526–1857)[2] brought them in direct contact with their Persianate counterparts as they both jostled for imperial sponsorship.[3] The Mughal emperors instituted translation projects that offered the opportunity of employment or endorsement to a newly emergent class of professional astronomers and bilingual interpreters. It is in this competing cosmopolitan world of Mughal India that Sanskrit astronomy truly begins to engage with Islamicate (Arabic and Persian) ideas.[4] The complex discourses that followed were shaped by the power struggles of language, culture, and identity as medieval Islamicate astronomy was now cast into the language of Sanskrit.

At the court of Mughal Emperor Shāh Jahān (r. 1628–1658), the Hindu Pandit Nityānanda (fl. 1630/1650) worked alongside the Muslim scholar Mullā Farīd al-Dīn Dihlavī (d. ca. 1629/1632) to translate into Sanskrit the latter's Persian *zīj* (a handbook of astronomical tables), the *Zīj-i Shāh Jahānī* (ca. 1629/1630), itself based upon the famous *Zij-i Jadīd-i Sulṭānī* (ca. 1438/1439) of Mirzā Ulugh Beg. Nityānanda's *Siddhāntasindhu* 'The Ocean of *siddhānta*s' (ca. early 1630s), like the

DOI: 10.4324/9780429506680-1

Zīj-i Shāh Jahānī, is an enormous work that includes theoretical discussions on hermeneutics, logic, metaphysics, mathematics, and astronomy, along with a large number of astronomical, calendrical, and geographical tables. It is the largest (and among the earliest) Sanskritic presentation of Islamicate astronomy composed in the style of an Islamicate *zīj*.

With the *Sarvasiddhāntarāja* 'The King of all *siddhānta*s' (1639), a later adaptation of his *Siddhāntasindhu*, Nityānanda reformulated his ideas to follow the material and the metrical standards of a traditional canonical treatise (*siddhānta*) in Sanskrit astral sciences (*jyotiḥśāstra*).[5] The contents of the *Sarvasiddhāntarāja* are arranged in three main chapters (*adhyāya*s), namely, the *gaṇitādhyāya* 'chapter on computations', the *golādhyāya* 'chapter on spheres', and the *yantrādhyāya* 'chapter on instruments'. The *golādhyāya* provides the geometrical basis to understand the computational methods for planetary motion described in the *gaṇitādhyāya*, while the *yantrādhyāya* describes the methods of construction of various astronomical instruments. The work is entirely composed in Sanskrit metrical poetry with verses of various lengths in an assortment of complex metres. By integrating Islamicate views (*yāvanika-mata*) with traditional Sanskrit canonical opinions (*saiddhāntika-mata*) and mythohistorical narratives (*paurāṇika kathā*), Nityānanda demonstrates a creativity, originality, and innovation hitherto rarely seen in any Sanskrit text on astronomy.[6] In fact, the transformation of Islamicate astronomy to suit the linguistic and ontological paradigms of traditional Sanskrit science makes Nityānanda's *Sarvasiddhāntarāja* a unique experiment in syncretic epistemology where mathematics, mythology, and modernity contend and cooperate simultaneously.

The present book provides, for the very first time, a critical edition and an English translation (accompanied by critical notes and technical analyses) of the contents of the 'chapter on spheres' (henceforth, called the *golādhyāya*) from Nityānanda's *Sarvasiddhāntarāja*. In the *golādhyāya*, Nityānanda describes (i) the different types of spheres, namely, the terrestrial sphere or the sphere of the Earth (*bhūgola*), the sphere of asterisms (*bhagola*), the oblique celestial sphere (*khagola*), and the visible celestial sphere (*dṛggola*); (ii) the great and small circles on these spheres that correspond to various terrestrial, chronometric, and astronomical measurements; and (iii) the mythohistorical accounts of geography and cosmography from Purāṇic sources.

Several topics discussed in this chapter are of Greco-Islamicate (Ptolemaic) origin; for example, the latitudinal division of the inhabited land (oecumene) on Earth into seven climes or the distribution of 48 constellations in relation to the ecliptic. Their inclusion in a seventeenth-century Sanskrit astronomical *siddhānta* is itself novel and unique for its time. There are some instances where Nityānanda rejects traditional world-views (based on the Purāṇas lit. the ancient word) in favour of more contemporary ones, whereas in other instances, he accepts both the mythohistorical and mathematical points of view as valid despite the inherent contradictions between them. In many ways, Nityānanda's attempts to reconcile heterogeneous opinions are a reflection of the changing episteme of early modern Sanskrit astronomy, and by examining the intricacies of his thoughts on spheres, this book hopes to bring to the fore some of the ways in which traditional Sanskrit astronomy functioned and flourished in early modern Mughal India.

1.1 Indian astronomy: a brief overview

Within India, the study of *jyotiḥśāstra* has enjoyed a rich history of scholarship: the various types of technical texts (e.g., *siddhānta*s, *karaṇa*s, *koṣṭhaka*s, *tantra*s), commentaries (*bhāṣya*s), and annotations (*vārttika*s) illustrate its capaciousness to include a diverse range of opinions.[7] However, within a global discussion on the history of science, the Indian contribution remains remarkably under-represented, especially when compared to the extent of similar studies across Babylonian, Hellenistic, and Islamicate cultures of science.[8] The lack of the availability of translations of technical Sanskrit literature (e.g., texts in mathematical astronomy) in modern-day languages has meant that the Indian contribution to the global history of science continues to remain peripheral and secluded. However, studies like Pingree (1963, 1973b, 1976b, 1978a, 1978b), Mak (2013), Mercier (2018), Gansten (2019, 2020) and Misra (2021, 2022) have demonstrated the interconnectedness of the study of astral sciences in India and the world. The study of Indian astronomy offers a perspective to examine the history of science in a society where the power struggles of sociocultural identities, linguistic hegemonies, and philosophical predispositions shape scientific discourses in unique ways.[9] Moreover, the changing geopolitical landscape of India has meant that there were extended periods of its history where traditional ideas were confronted with foreign theories. The ensuing arguments in accepting, accommodating, or repudiating these theories demonstrate the vitality of thought among Indian astronomers (see, e.g., Pingree 1996a and Minkowski 2002).

In contrast to the Greco-Islamicate practice of using kinematic celestial models, the study of astronomy in India focused on developing and improving numerical algorithms to calculate planetary motion. Its emphasis on computations allowed it to maintain a versatile structure without committing itself to any immutable ideals or geometrical forms. In fact, this approach was in line with the emphasis on memory and orality in Indian sciences. Technical texts were often composed in versified (metrical) Sanskrit for mnemonic purposes, and in mathematical astronomy, mastery was demonstrated by compositions that reflected both poetic elegance and numerical sophistication. This, however, is not to deny the importance of geometry in Indian mathematical astronomy: on the contrary, epicyclic and eccentric planetary models from non-Ptolemaic traditions made their way into Sanskrit *siddhānta*s as early as the fifth century (Pingree 1971). These models were developed and modified over time to match the computational advancement, in particular, in the works of the Kerala (Niḷā) school of astronomers and mathematicians (see, e.g., Shastri 1969, Shukla 1973, Ramasubramanian, Srinivas and Sriram 1994 and Ramasubramanian 1998).

Table 1.1 sketches an approximate chronology of the different periods in the history of Indian astronomy, as described in S. B. Dikshit (1969), Pingree (1978a), S. B. Dikshit (1981), Pingree (1981b), Subbarayappa and Sarma (1985), Rao (2000), Sen and Shukla ([1985] 2000), Plofker (2009) and Divakaran (2018) all of which, taken together, survey the field fairly exhaustively. A significant aspect of Indian astronomy is the origin, development, competition, and coexistence of different schools of thoughts called *pakṣa*s in the medieval India. The differences between the *pakṣa*s were based on their choice of astronomical parameters, e.g., the integer number of complete rotations indicating the mean motions of the planets (over very large cyclical periods of time called *yuga*s). The proponents of these *pakṣa*s wrote foundational and canonical treatises (*siddhānta*s) that differed on specific computational nuances, e.g., on the effect of double-epicyclic forces acting on the mean positions of planets and causing their longitude to dislocate towards their true positions (Pingree 1971).[10] By the middle of the second millennium, the corpus of technical astronomical texts in Sanskrit grew to include commentaries (*bhāṣya*s), technical expositions (*tantra*s), disquisitions (*pradīpikā*s), annotations (*vārttika*s), compendiums (*sāra*s or *saṅgraha*s), book on rationales (*yukti*s), logic (*nyāya*s), explanatory guides (*vivaraṇa*s), and mnemonic aphorisms (*sūtra*)—all of these based on commenting or critiquing the canonical texts.

Along with these exegetical texts, shorter (and more concise) texts called *karaṇa*s were written with a stronger emphasis on practical rules of computations. The production of these *karaṇa*s led to a profusion of simpler astronomical table-texts (*sāraṇī*s or *koṣṭhaka*s) written for the benefit of practical astronomy (see, e.g., Montelle and Plofker 2018). These table-texts became standard reference books for fortune-tellers, priests, and astrologers who, in turn, composed additional calendrical, astrological, and divinatory texts for practical purposes, namely, almanacs and ephemerides (*pañcāṅga*s); books of omens (*saṃhitā*s); and texts on genethlialogy (*jātaka-paddhati*), catarchic astrology (*muhūrta-paddhati*), and interrogations (*praśna-vicāra*).

Towards the middle of the second millennium, Islamicate astronomy from the Marāgha and Samarqand schools began circulating in the centres of learning in northern India. Sanskrit astronomers, particularly those under the direct or indirect patronage of the Mughal courts (more on this in Section 1.1.3), debated the validity and utility of this foreign astronomy in their works.[11] It is here that we find seventeenth-century Hindu astronomers like Nityānanda (fl. 1630/1650), Munīśvara

Table 1.1 An approximate chronology of the periods in the history of Indian astronomy

Date	*Period*	*References*
BCE		
ca. *ante* 2000	Indus Valley Civilisation	Ashfaque (1977) and Vahia and Menon (2011)
ca. 1500–1000	Ṛg Vedic Period	S. B. Dikshit (1969) and Ôhashi (1993)
ca. 1000–500	Late Vedic Period	
ca. 500–300	Beginnings of *Vedāṅga* Astronomy	
CE		
ca. 100–200	Introduction of Greek Horoscopy	Pingree (1978d)
ca. 200–400	*Vedāṅga* Astronomy	Ôhashi (2002)
ca. 400	Introduction of Greek Mathematical Astronomy	Pingree (1978a)
ca. 500–1200	Canonical (*saidhhāntika*) Astronomy	S. B. Dikshit (1981)
ca. 1200/1300–1700/1800	Indian and Islamicate Astronomy	Ansari (1995), Rahman (1998), and Ansari (2005, 2016)
ca. post 1700	Indian and European Astronomy	Ansari (1985), Kochhar and Narlikar (1995) and Sen and Shukla ([1985] 2000)

(fl. 1646), and Kamalākara (fl. 1658) composing their own canonical works that engage with Islamicate ideas in different ways. The separation or syncretism of Indian and Islamicate astronomy seen in their writings offers a liminal perceptive on the linguistic, cognitive, and societal challenges that impact Sanskrit mathematical astronomy in the seventeenth century.

1.1.1 Medieval Siddhāntic astronomy, ca. 400–1600

Towards the end of the first millennium, the computational techniques and planetary models in Indian astronomy were influenced by Hellenistic (non-Ptolemaic) astronomy. These influences can be observed in the different subdisciplines of mathematical astronomy, e.g., in the techniques of trigonometry, spherical geometry, algebraic inequalities, and indeterminate equations (see Pingree 1963, 1978a, 1981b). Their subsequent utility brought the systematisation of the different schools of thought called *pakṣa*s, where each *pakṣa* used a slightly different set of astronomical parameters to describe celestial phenomena (see, e.g., Pingree 1970b). A detailed description of the different *pakṣa*s discussing their parametric differences and mathematical innovations is described elsewhere, e.g., in Pingree (1978a) and Plofker (2009). Table 1.2 lists the main texts (*siddhānta*s and *karaṇa*s) and their authors that represent the different *pakṣa*s. These texts often borrowed, amalgamated, or refuted ideas from among each other, and came to define what we collectively call the corpus of Siddhāntic (*saidhhāntika/pākṣika*) astronomy. The adherents of these *pakṣa*s created a medieval knowledge economy in their writings where computational rules were often commutable and parametric values commensurable.[12] In many ways, their proclivity for ideational equipoise fostered the environment where Islamicate ideas could also be discussed and debated in the Siddhāntic astronomy of the early modern age (see, e.g., Pingree 1963, 1978c, 1996a).

1.1.2 Early modern Siddhāntic astronomy, ca. post 1600

Beginning from the late fourteenth century and culminating in the early eighteenth century, astronomical tables (*zīj*es), observational instruments, and planetary models of Islamicate origin increasingly influenced Sanskrit astronomy (particularly, in North India).[13] While some Sanskrit works were direct translations of Arabic or Persian texts (see, e.g., Misra 2021, Table 1 on p. 40), others were more subtle in discussing Islamicate theories (see, e.g., Pingree 1978c, 1996a, 1999). The exegetical texts and commentaries that ensued is a hallmark of the tumultuous reception of Islamicate theories in Sanskrit. Of particular note are two seventeenth-century immigrant families of Devarāta and Bhāradvāja Brahmins in Kāśī (modern-day Varanasi), led by Munīśvara

Table 1.2 A chronology of some of the major texts in the different schools (*pakṣa*s) of medieval and early modern Siddhāntic astronomy, ca. 400–1700

School (pakṣa)	*Texts*
Brāhmapakṣa	*Paitāmahasiddhānta* of Viṣṇudharmottara Purāṇa (ca. fifth century) *Brāhmasphuṭasiddhānta* of Brahmagupta (628) *Mahāsiddhānta* of Āryabhaṭa II (ca. 950–1000) *Siddhāntaśekhara* of Śrīpati (ca. mid eleventh century) *Siddhāntaśiromaṇi* of Bhāskara II (1150) *Karaṇakutūhala* of Bhāskara II (1183) *Laghukaraṇa* of Bhāvasadāśiva (1598) *Karaṇavaiṣṇava* of Śaṅkara (1766)
Āryapakṣa	*Āryabhaṭīya* of Āryabhaṭa I (499) *Mahābhāskarīya* and *Laghubhāskarīya* of Bhāskara I (ca. early seventh century) *Śiṣyadhīvṛddhidatantra* of Lalla (ca. eight/ninth century) *Vaṭeśvarasiddhānta* of Vaṭeśvara (904) *Karaṇaprakāśa* of Brahmadeva (1092) *Tantrasaṅgraha* of Nīlakaṇṭha Somayājī (1501)
Ārdharātrikapakṣa	*Āryabhaṭasiddhānta* of Āryabhaṭa I, *lost* (ca. 500) *Sūryasiddhānta* (a revised version preserved in the Varāhamihira's *Pañcasiddhāntikā*, ca. sixth century) by Lāṭadeva (ca. 505) *Khaṇḍakhādyaka* of Brahmagupta (665) *Bhāsvatī* of Śatānanda (1099)
Saurapakṣa	*Sūryasiddhānata* unknown authorship (ca. 800), most common recension by Raṅganātha of Benaras (1602) *Laghumānasa* of Muñjāla (ca. 932) *Sūryasiddhāntaṭīkā* of Mallikārjuna Sūri (1178) *Somasiddhānta* of Nṛsiṃha (ca. 1400) *Sūryasiddhāntavivaraṇa* of Parameśvara (1432) *Siddhāntasundara* of Jñanarāja (1503) *Rāmavinoda* of Rāmacandra (1590) *Sūryapakṣaśaraṇa* or *Khacarāgama* of Viṣṇu (1608) *Siddhāntasarvabhauma* of Munīśvara Viśvarūpa (1646) *Siddhāntatattvaviveka* of Kamalākara (1658) *Sauravāsanā* on the *Sūryasiddhānata* by Kamalākara (*post* 1658)
Gaṇeśapakṣa	*Grahalāghava* or *Siddhāntarahasya* of Gaṇeśa Daivajña (1520) *Karaṇakaustubha* of Kṛṣṇa Daivajña (1653)

(b. 1603) and Kamalākara (b. 1610) respectively, who argued the validity of Islamicate ideas vigorously. The rivalry between these two scholastic families saw several texts being authored by extended family members assailing each other (see Minkowski 2014, pp. 122–127). For instance, Raṅganātha, the brother of Kamalākara, wrote his *Lohagola-khaṇḍana* 'Critique of the Sphere of Iron' rejecting the orthodox Indian view that the blue sky was, in fact, a sphere of iron (*loha-gola*) and accepting in place the Persian view (*pārasīka-mata*) that it was a crystalline sphere (*sphaṭika-gola*). In response to this, Gadādhara, Munīśvara's cousin, promptly composed his *Lohagolasamarthana* 'Vindication of the Sphere of Iron' as a dissenting rejoinder.

1.1.3 Siddhāntic astronomy in the Mughal world

The *Gurkānī ᶜĀlam* or the Mughal world (1526–1857) was the rule of the Muslim emperors in South Asia led by monarchs of the Timurid dynasty, beginning with Ẓahīr al-Dīn Muḥammad Bābur. The successors of Bābur extended their dominion over the Indian subcontinent, and in doing so, they created a cosmopolitan society where artistic, literary, and scientific traditions from different cultures thrived and flourished. The practice of translating literary and technical texts between Sanskrit and Persian became an administrative activity under the patronage of successive Mughal emperors. In fact, as early as the fourteenth century, Sanskrit literary works were translated into Persian under the sponsorship of the Turkic Sulṭāns of Delhi; for example, the *Tūtīnāma* 'Tales of a Parrot' of Ẓīyāᵓ al-Din Nakhshabī (d. 1350) was a collection of 52 short stories in Persian adapted from the Sanskrit *Śuka-saptati* 'Seventy tales of the Parrot' (ca. twelfth century) under the patronage of Sulṭān Muḥāmmad bin Tughlaq (1325–1351). Modern-day scholars like Alam (2003), Haider (2011), Truschke (2012, 2015, 2016), and Nair (2020)have described the complex sociocultural world of Mughal India where Sanskrit and Persian literary traditions cohabited and contested for power, privilege, and position. These studies also describe the culture in which technical Sanskrit texts were translated into Persian at the behest of Mughal emperors; for example, Bhāskara II's treatise on arithmetic, the *Līlāvatī* (1150), was translated into the Persian as the *Tarjuma-yi Līlāwatī* in 1587 by Abu ᵓl-Fayḍ Fayḍī at the court of the Mughal Emperor Akbar (r. 1556–1605). By the time Nityānanda's patron, Emperor Shāh Jahān (r. 1628–1658), ascended to the throne, his predecessors had already started a custom of decorating Sanskrit court astrologers with titles likes 'royal astronomer' (*Jotik Rāi* or *Vedāṅgarāya*). Even Shāh Jahān conferred such a title on

Mālajit Vedāṅgarāya (fl. 1643), a reputable Hindu Pandit from Kāśī who entered the service of Shāh Jahān's court at the recommendation of his former patron Rāja Giridhara Dāsa, the Rajput King of Ajmer (Minkowski 2014, pp. 121–122).

Under Shāh Jahān's rule, the Hindu Brahmin community continued to participate in various cultural and courtly affairs. For example, there were two Hindi-speaking Brahmin poets at Shāh Jahān's court, Kavīndrācārya Sarasvatī Vidyānidhāna (fl. ca. 1600/1675) and Jagannātha Paṇḍitarāja (fl. ca. 1620/1660), who ingratiated themselves with the emperor and his retinue by composing panegyrics in Brajabhāṣā and singing Hindustānī *dhrupad* songs at his court (Truschke 2016, pp. 50–53). As Pollock (2001) observes, the seventeenth century saw an 'explosion of scholarly production unprecedented for its quantity and quality' (p. 5) by new intellectuals (*navya*, *navīna*, or *arvāc*) in the fields of grammar, hermeneutics, and logic (the classical Sanskrit *trivium*) as well as literary theory and rhetoric. Moreover, the intellectual curiosity and scientific revolution that pervaded the seventeenth century made the business of intellectual exchange a very profitable venture (see, e.g., Huff 2010). The Hindu Pandit Mālajit Vedāṅgarāya who was decorated by Shāh Jahan was also the author of a *Pārasiprakāśa* (1643), a Sanskrit lexicon for translating Persian astronomical terms. A functional multilingualism in Persian, Sanskrit, and vernacular Hindi would have been a competitive and cultural advantage for any aspiring Hindu astrologers (*jyotiṣī*s) vying for Mughal sponsorship.[14]

However, even as the political and linguistic world of seventeenth-century Mughal India promoted cross-cultural exchanges between Sanskrit and Islamicate astronomy (see, e.g., Misra 2021, pp. 33–42), it encountered the resistance of scientific traditionalism. The revelations of the sages (*śrutivāda*) in the Sanskrit *siddhānta*s were meant to preserve ancient Hindu belief systems, and in many instances, they were in opposition to the opinions of the foreigners (*yāvanika-mata*). This created a conceptual battle between opposing adherents. The rivals Munīśvara and Kamalākara both held differing opinions on Islamicate astronomy: Munīśvara, in his *Siddhāntasārvabhauma* (1646), strongly disparaged certain Islamicate ideas (e.g., the Islamicate theory of zodiacal precession implying a tropical zodiac instead of a sidereal one) for being understood subjectively (*svamata*) and defying the revelation of the sages (*ṛṣimata-viparīta*), whereas Kamalākara offers a more tolerant, utilitarian, and pluralistic acceptance of the Islamicate imports in his *Siddhāntatattvaviveka* (1658) (Pingree 1978c, pp. 320–323). As Section 1.2 describes, Nityānanda's efforts in his *Sarvasiddhāntarāja* are more ameliorative as he attempts to reconcile Islamicate and Siddhāntic astronomy.

1.2 The *Sarvasiddhāntarāja*, 'The King of all *siddhānta*s'

According to the *Mulakhkhaṣ-i Shāhjahān Nāma*, the chronicles of Emperor Shāh Jahān, the astronomical tables called the *Zīj-i Shāh Jahānī* of Mullā Farīd al-Dīn Dihlavī (d. ca. 1629/1632) were to be translated into 'the language of Hindustan by Indian astronomers in consultation with Persian astronomers, for the sake of public utility'.[15] Mullā Farid, the 'wonder of the age' (*nādir al-zamān*), was a noted Islamicate astronomer (*munajjim*) who was recruited to compose the *Zīj-i Shāh Jahānī* at the behest of—or as the chronicles declare 'under the expert supervision' of—Āṣaf Khān, the prime minister (*vazīr-i āᶜẓam*) of Shāh Jahān and the 'right hand of the state' (*yamīn al-dawla*) (Begley and Desai 1990, p. 35).[16]

In his writings, Mullā Farid differentiated between astronomical tables (*zīj*es) that were composed by making actual observations (*raṣad*) of the distances, sizes, and positions of celestial objects and those that were simply based on mathematical calculations (*ḥisāb*): the former was called a *zīj-i raṣadi*, while the latter was known as a *zīj-i hiṣābi* (Ghori 2008, pp. 385–386). Mullā Farīd's *Zīj-i Shāh Jahānī* was a *zīj-i hiṣābi* where he modified the set of astronomical tables of Ulugh Beg (*Zīj-i Jadīd-i Sulṭānī*, better known as *Zīj-i Ulugh Beg*) composed by the consortium of ᶜAlī Qūshjī, Jamshīd al-Kāshī, and Qāḍīzāda al-Rūmī at the observatory in Samarqand in 1438/1439 under the supervision of Sulṭān Ulugh Beg himself.[17] The *Zīj-i Shāh Jahānī*, following the *Zīj-i Ulugh Beg*, contains four discourses (*maqāla*s) on four different subjects each containing several chapters (*bāb*s) that are further divided into sections (*faṣl*s).[18]

Mullā Farīd is believed to have completed the *Zīj-i Shāh Jahānī* and presented it to the emperor around October/November of 1629 (month of *Rabīᶜ al-awwal* in the Hijrī year 1039).[19] This work instituted a new calendar, the *Tāʾrīkh-i Ilāhī Shāhishānī*, commencing on 14 February 1628, the day of the coronation of Shāh Jahān (Begley and Desai 1990, p. 35). The *Zīj-i Shāh Jahānī* included the astronomical tables (and canons) of *Zīj-i Ulugh Beg* with little modification; however, it also contained an extensive list of eras (including Akbar's Ilāhī era and the Indian Vikrama Saṃvat) and a comprehensive list of festivities and occasions (Blake 2013, p. 64). The Mughal court chronicler Muḥammad Sāleḥ Kambūh praised the *Zīj-i Shāh Jahānī* as being superior to the *Zīj-i Ulugh Beg* and hence supplanting the latter in regular use. This prompted Shāh Jahān to decree that Mullā Farīd's *Zīj-i Shāh Jahānī* be translated into Sanskrit for use among the Hindu astronomers in his kingdom (Ghori 2008, p. 397).

The responsibility of translating the *Zīj-i Ulugh Beg* into Sanskrit fell upon the Hindu Pandit Nityānanda Miśra (fl. 1630/50), a Gauḍa Brahmin of Mudgala *gotra* (patronymic) from Indrapurī (Old Delhi).[20] Nityānanda was commissioned to this task by Shāh Jahān's Prime Minister Āṣaf Khān. He dedicated himself to the task and soon after, in the early 1630s, he presented his Sanskrit translation the *Siddhāntasindhu*

'The Ocean of *siddhānta*s'.[21] Misra (2021) examines the linguistic affinity between the Sanskrit verses in Nityānanda's *Siddhāntasindhu* and corresponding Persian passages in Mullā Farīd's *Zīj-i Shāh Jahānī* to suggest how technical familiarity, conceptual affordance, and vernacular conviviality all played their parts in this exercise of translating Islamicate astronomy into Sanskrit.

Despite his efforts, Nityānanda's *Siddhāntasindhu*, with its Sanskritised presentation of an Islamicate table-text, failed to make a discernible impact on the Sanskrit astronomers of his time. In the years that followed, Nityānanda made a second more dedicated attempt to adapt Islamicate astronomy to Sanskrit and called it the *Sarvasiddhāntarāja*, 'The King of all *siddhānta*s'.[22] The *Sarvasiddhāntarāja* differed from the *Siddhāntasindhu* in its presentation of Islamicate astronomy, in particular, in its use of metrical Sanskrit verses in composition (as was expected of a traditional Sanskrit *siddhānta*) and citing Islamicate parameters and procedures from allonymous works.

1.2.1 Nityānanda, the Hindu Brahmin

There is very little biographical information known about Nityānanda. On the basis of the colophon seen at the end of the manuscripts of the *Sarvasiddhāntarāja*, and cited in secondary sources like S. Dvivedī (1933, pp. 101–102), S. B. Dikshit (1981, pp. 165–166), and CESS A3 (1976a, p. 173b), we learn that Nityānanda was a Gauḍa Brahmin of the Mudgala *gotra*.[23] He was a resident of Indrapurī, an epithet for the city of Old Delhi, a place known to be in close proximity to the historic city of Kurukṣetra (in modern-day Haryana). The colophon also states that Nityānanda was trained in the tradition of Ḍulīnahaṭṭa, which, according to S. Dvivedī (1933), could indicate Nityānanda's place of origin. Dulīna is a village (perhaps, identified with the city of Jhajjar) in the district of Jhajjar/Rohtak in Haryana, around sixty kilometres west of Old Delhi (Indrapurī).[24]

The patrilineage of Nityānanda is stated as follows: Nityānanda, son of Devadatta, son of Nārayaṇa, son of Lakṣmaṇa, son of Icchā. Beyond their names, we know nothing about Nityānanda's ancestors or any texts they may have authored. Nityānanda, however, is believed to have authored the following four texts.

1 The *Siddhāntasindhu* (ca. early 1630s), see CESS A3 (1976a, pp. 173b), CESS A4 (1981a, p. 141ab), and CESS A5 (1994, p. 184a).

2 The *Sarvasiddhāntarāja* (1639), see CESS A3 (1976a, pp. 173b–174a), CESS A4 (1981a, p. 141b), and CESS A5 (1994, p. 184a).

3 The *Śāhajahāṃgaṇita* (unknown date), see CESS A3 (1976a, p. 174a).

4 The *Aṃrtalaharī* (ca. 1649/50), see CESS A1 and A2 (1970a, p. 46a in Volume A1) where this work is (erroneously) catalogued under the name 'Aṃrtalāla'.

1.2.2 Structure and contents of Sarvasiddhāntarāja

Nityānanda composed his *Sarvasiddhāntarāja* (in Vikrama Saṃvat 1696, Śaka 1561, 1639 CE) in the style of a traditional Sanskrit *siddhānta* in *jyotiḥśāstra*. It includes discussions on the topics of mathematics, astronomy, and calendrics that are grouped under three chapters (*adhyāya*s), namely, the *gaṇitādhyāya* 'chapter on computations', the *golādhyāya* 'chapter on spheres', and the *yantrādhyāya* 'chapter on instruments'. The *gaṇitādhyāya* is the largest chapter in this work and it includes separate topical sections (*adhikāra*s) that discuss the astronomical parameters and mathematical procedures governing planetary motion. The *golādhyāya*, typically following the *gaṇitādhyāya*, discusses the underlying geometry and theory behind the computational methods described in the first chapter. The *yantrādhyāya* (sometimes regarded as being of the *golādhyāya*) is the last chapter on the methods and materials of constructing astronomical instruments. Taken together, these three chapters offer a systematic examination of all the major topics discussed in Sanskrit mathematical astronomy. Table 1.3 lists the topics discussed in the different sections of the three chapters of the *Sarvasiddhāntarāja*.[25]

Each chapter begins with a different benedictory verse (*maṅgalācaraṇa*) that announces an auspicious beginning and also demarcates the chapters (as separate parts of the book). The end of the chapters, and the end of each topical section in the *gaṇitādhyāya*, contains a (near) similar colophon that reads

> *ity etasyām indrapuryāṃ vasan sannityānando devadattasya putraḥ* |
> *sāroddhāre sarvasiddhāntarāje* ____ *prāpayat tatra pūrtim* ||
>
> In this manner, the wise Nityānanda, the son of Devadatta, residing in this city of Indrapurī, caused the ____ to attain completion there in the quintessential *Sarvasiddhāntarāja* [lit. king of all treatises].[26]

The blank space in the verse above is the name of the particular chapter or topical section just completed. The colophons at the end of the individual sections of the *yantrādhyāya* read

> *iti yantraraje* ____*-adhyāyaḥ* |
>
> Thus ends the reading of ____ in the (*Yantrarāja*) [lit. king of all instruments].

Table 1.3 The contents of the *Sarvasiddhāntarāja*

Sarvasiddhāntarāja (1639) of Nityānanda		
Chapter (*adhyāya*)	*Section* (*adhikāra*)	
I. *gaṇita* 'computations'	1 *mīmāṃsā*	'philosophical reflections'
	2 *madhyama*	'mean positions of planets'
	3 *spaṣṭa*	'true positions of planets'
	4 *tripraśna*	'three question: direction, place, and time'
	5 *candragrāsa*	'lunar eclipses'
	6 *sūryagrāsa*	'solar eclipses'
	7 *śṛṅgonnati*	'elevation of the lunar cusps'
	8 *saṃkrānti*	'conjunctions'
	9 *spaṣṭakrānti*	'true declination'
	10 *dṛkkheṭa*	'visibility of the planets'
	11 *bhānāṃ jñāna*	'knowledge of the stars'
II. *gola* 'sphere'	*bhūgola*	'sphere of Earth'
(list of topic, see Section 1.3.1)	*bhagola*	'right celestial sphere'
	khagola	'oblique celestial sphere'
	dṛggola	'visible celestial sphere'
III. *yantra* 'instruments'	1 *gaṇita*	'computations'
	2 *ghaṭanā*	'fabrication'
	3 *racanā*	'composition'
	4 *śodhana*	'corrections'
	5 *nirīkṣaṇa*	'examination'

1.2.2.1 *An overview of the Sarvasiddhāntarāja*

1 Nityānanda begins the *gaṇitādhyāya* by discussing the philosophical rationales (*mīmāṃsā*) of Siddhāntic astronomy. There, he begins by making his epistemic standards explicit (more on this in Section 1.2.3), and then goes on to describe his preference for the tropical (*sāyana*) zodiac over the sidereal (*nirayaṇa*).[27] Right at the beginning, these discussions reveal Nityānanda's consonance with foreign opinions (*yāvanika-mata*) which then becomes more evident in the ensuing technical discourse. The remaining sections in the *gaṇitādhyāya* discuss several Islamicate ideas in a complex narrative that tries to syncretise the Greco-Islamicate and Sanskrit Siddhāntic traditions of mathematical astronomy. For example, in the section on true declination (I.9 *spaṣṭakrānti*), Nityānanda proposes three methods to compute the correct declination of a

celestial object. These methods are described in Sanskrit verses that are copied near-verbatim from his *Siddhāntasindhu* (II.6), which, in turn, contains Sanskrit translations of corresponding Persian passages from Mullā Farīd's *Zīj-i Shāh Jahānī* (II.6) (see Misra 2022).

In the various sections of the *gaṇitādhyāya*, Nityānanda also provides several proofs/demonstrations (*upapatti*s) and examples (*udāharaṇa*s) to supplement his technical discussions. For example, verses I.3.19, 42, 50, 153, 200; I.4.42, 45, 53; and I.5.56, 61, and 82 are *upapatti*s while verses I.3.83; I.4.31, 115, 131, 146, 154; and I.5.12 are *udāharaṇa*s.[28] The proofs and examples in these discussions suggest that the *Sarvasiddhāntarāja* was not just a scholarly text, but it was also intend for pedagogical use.

The overarching theme of the *gaṇitādhyāya* is reconciliatory: Nityānanda attempts to bring the astronomical parameters and models of the *Brāhmapakṣa* and the *Saurapakṣa* to harmonise with what he understands as Islamicate equivalents from the Roman *zīj* or *Romakasiddhānta*. For example, in the section on mean positions (I.2 *madhyama*), he provides numerical corrections (*bīja*s) to make the epoch mean longitudes of the planets in the *Romakasiddhānta* equal to those attested in the *Brāhmasphuṭasiddhānta* and *Sūryasiddhānta* (see Pingree 2003b, Table 9.7 on p. 275). Elsewhere, e.g., in the section on true positions (I.3 *spaṣṭa*), Nityānanda introduces Islamicate model of planetary motions with their equants, protective spheres, and lunar crank mechanisms, as well as the Aristotelian description of the elemental spheres that constitute the physics of the universe using novel technical vocabulary and subtle mathematical trickery (see Pingree 1978c, p. 325).

2 The numerical algorithms and mathematical procedures described in the *gaṇitādhyāya* are based on the geometrical properties and trigonometric proportions of the various circles drawn on a sphere. Understanding the science of spheres allows an astronomer to understand the foundations of the astronomical calculations, and, accordingly, be better qualified to practise professionally. In the *golādhyāya*, Nityānanda describes various aspects of the celestial sphere, beginning with a detailed description of the sphere of Earth (*bhūgola*) from an astronomical, geographical, and mythohistorical (Purāṇic) perspective. Following this, the various orientations of the celestial sphere, namely, the right celestial sphere (*bhagola*), the oblique celestial sphere (*khagola*), and the visible celestial sphere (*dṛggola*), are discussed assiduously. Section 1.3.1 provides a more elaborate description of the contents of the *golādhyāya*.

3 The *yantrādhyāya* (sometimes referred to by its own title the *Yantrarāja* 'The King of Instruments') includes topics that discuss the mathematics, fabrication, calibration, precision, and use of various astronomical instruments.

1.2.3 *The episteme of the Sarvasiddhāntarāja*

In the Sanskrit *jyotiṣa* tradition, *siddhānta*s are a class of canonical astronomical treatises with an epoch date corresponding to the beginning of the *kaliyuga* 'age of *kali*', around 3102 BCE.[29] The *Sarvasiddhāntarāja* is one of the earliest Sanskrit *siddhānta*s that discuss Islamicate astronomy. It does so in a language the acknowledges the plurality (*anaikya*) of opinions (*mata*) in the various traditions (*pākṣa*s) of Sanskrit Siddhāntic astronomy. While Nityānanda's *Sarvasiddhāntarāja* is based on his table-text *Siddhāntasindhu*, it is also different from the latter in being a historical exegesis of Siddhāntic astronomy. By presenting multiple opinions in parallel (Greco-Islamicate, being one of them), Nityānanda offers an overview of the Indian and Islamicate astronomical theories prevalent in his times. The comparability of these theories facilitates their syncretism in the *Sarvasiddhāntarāja*, and this, in turn, motivates the epistemological question: what is a valid source of (astronomical) knowledge and how is it tested?

1.2.3.1 *Revelation as divine testimony*

In classical Indian philosophy, the means (*pramāṇa*) to acquire true knowledge (*pramā*) has been a subject of great discussion.[30] In describing testimony (*śabda*, lit. word) as an instrument of true knowledge, Akṣapāda Gautama, in his *Nyāyasūtra* (I.1.7, ca. between sixth century BCE and second century CE), says *āptopadeśaḥ śabdaḥ* '*śabda* is the testimony (*upadeśa*) of an authoritative or credible person (*āpta*)'. Commenting on this statement, Vātsyāyana (fl. ca. 450–500) describes *āpta* as someone who directly apprehends the truth and is driven by a natural desire to communicate it to others without distortion. Thus, trustworthiness (*āptabhāva*) can be extended to all credible sources: seers (*ṛṣi*s), noble men (*ārya*s), and foreigners (*mleccha*s).[31]

In Sanskrit *jyotiḥśāstra*, foreign ideas were (partially) accepted from very early times, and often, the authors of these ideas were designated as ancient seers to justify their testimony as divine revelations. For example, Varāhamihira, in his *Bṛhat Saṃhitā* (ca. sixth century), accords the status of a seer (*ṛṣi*) to those foreigners (*yavana*s, *pārasīka*s, or *mleccha*s) who are well versed in the study of sciences (*śāstra*s).[32] According to Varāhamihira, an education in the *śastra*s is what makes a *yavana* a sagacious scholar—despite their lowly (*mleccha*) origins—and comparable to a Brahmin Pandit. While some Siddhāntic scholars agreed with this secular meritocratic view, there were many who maintained the orthodox (*smārtika*) position that the words of the *yavana*s were blasphemous and worthy of disavowal.

One of Nityānanda's contemporary, Balabhadra criticises this position in his *Hayanaratna* (1649).[33] In his critique, he relies on value of traditional testimony, predictive utility, and mythological narratives to make the teachings of the *yavana*s authoritative, efficacious, and revelatory. For example, by including Yavanācārya (lit. the preceptor called Yavana), the author of a *tājika* text in the lineage of semi-divine sages, Balabhadra makes Yavanācārya's statements authoritative, prophetic, and divine, even if they use Persian (*pārasīka*) words (see, e.g., Pingree 1997, pp. 86–87).[34] In a sense, Balabhadra's position on accepting foreign ideas in Sanskrit *jyotiḥśastra* is not a denial of traditionalism but a nuanced way of justifying the *śāstric* tradition itself.[35] When applied to *jyotiḥśāstra*, practical (*vyāvahārika*) and utilitarian (*aupayaugika*) concessions allow for verifiable improvements to mundane sciences (*laukika-śāstra*s). In matters of spiritual (*ādhyātmika*), moral (*dhārmika*), and ritual (*vaidhika*) concerns, the canonical authority of the *smṛti* texts is infallible and immutable.

Like Balabhadra's Yavanācārya, Nityānanda also situates Romaka among a lineage of gods (*sura*s) and semi-divine sages (*ṛṣi*s). In his *Sarvasiddhāntarāja* (I.1.2), he claims that

> *śrīsūryasomaparameṣṭhivasiṭhagargācāryātriromakapulastyaparāśarādyaiḥ* |
> *tantrāṇi yāni gaditāni jayantāni sphūrjaddvidhāgaṇitagolaparisphuṭāni* ||
>
> Those treatises that were proclaimed by the excellent [gods] Sūrya, Soma, Parameṣṭhi [and the *ṛṣi*s] Vasiṣṭha Garga, Atri, Romaka, Pulastya, and Parāśara, all of them are victorious, bursting into the two parts prominently seen as computations and spheres.

Here, Romaka is elevated to join the ranks of the ancient Hindu sages Vasiṣṭha, Garga, Atri, Pulastya, and Parāśara, and therefore, his *Romaka-siddhānta* is to be regarded as a revelatory text.

To extol Romaka's divine antiquity, Balabhadra, in his *Hayanaratna*, invokes the myth of the Hindu Sun god Sūrya who, having learnt astronomy from Brahmā and being afflicted by a curse, is born among the *yavana*s (or *mleccha*s) in a place called Romaka (or Roma). There, he teaches what he learnt from Brahmā to a *yavana* and thus it comes to pass that the revelation of Brahmā finds in way into the writing of Romaka (variously called *Romakazīj*, *Romakatājika*, or *Romakasiddhānta*).[36] Nityānanda repeats this myth in his *Sarvasiddhāntarāja* (I.1.16–18) saying

> *atha kaḥ kila romako bhavan munidevādiṣu gaṇyate tu yaḥ* |
> *kathayāmi tadīyam uttaraṃ śṛṇu sūryāruṇapūrvasammatam* ||

itihāsakathāprasaṅgato vidito bhāskara eva romakaḥ |
puruhūtavirañciśāpato yavano romakapattanaṃ bhavat ||

punar eva tayor anugrahāt cyutaśāpaḥ savitā svayaṃ purā |
kṛtavān iha tantram uttamaṃ śrutirūpaṃ kila romakachalāt ||

Now, who indeed is [this] Romaka who is counted among the sages, the gods, etc.? I shall speak of him; listen [then to what has been] previously agreed by Sūrya and Aruṇa,...

...on account of their fondness for legendary stories. Indeed Bhāskara [i.e., Sūrya] was known as Romaka due to a curse of Puruhūta [i.e., Indra] and Virañci [i.e., Brahmā]. Yavana [i.e., Romaka] being in the city of Romaka,...

...[and] then, becoming free of the curse due to the favour of those two gods, Savitṛ [i.e., Sūrya] himself composed in ancient times the foremost treatise here, which has the form of the [sacred] *śruti* texts even if [it is] in the guise of [a text composed by] Romaka.

Nityānanda attributes this story to a previous work, the *Jñānabhāskara* or *Sūryāruṇasamvāda*, a dialogue between the Sūrya and his charioteer Aruṇa, wherein we are told that Sūrya, being cursed by Brahmā to be born among the *yavana*s, revealed the *Romakasiddhānta* to one Romaka, who then revised it while living in a city called Romakanagara (Pingree 1978c, p. 324). For Balabhadra, the *Romakasiddhānta* is, perhaps, an astrological text (that is part of a *Śrīṣavayaṇasaṃhitā*); however, for Nityānanda, the *Romakasiddhānta* appears to an Islamicate text on astronomy (see, e.g., Misra 2022). As Pingree (1978c, p. 324) speculates, Nityānanda's Romaka could well be Qāḍīzāda al-Rūmī, one of Ulugh Beg's astronomer at Samarqand, who, along with ʿAlī Qūshjī and Jamshīd al-Kāshī, composed the *Zīj-i Ulugh Beg*. The influence of the astronomy of Ulugh Beg (perhaps, mediated through its recension in Mullā Farīd's *Zīj-Shāh Jahānī*) in Nityānanda's works is increasingly well documented (see, e.g., Montelle, Ramasubramanian and Dhammaloka 2016, Montelle and Ramasubramanian 2018, Misra 2021, 2022).[37]

The historicity of Romaka notwithstanding, Nityānanda's and Balabhadra's repetitions of mythopoeic tales involving him indicate the importance of such narratives. If revelation (*śruti*), understood as divine testimony (*śabda*), is to become an epistemic mean (*pramāṇa*) that is infallible (*amogha*), then the revelator (*śrutavid*, lit. knower of revelation) themself must be an authoritative or credible person (*āpta*). By being counted among the sacred *ṛṣi*s, Romaka acquires the moral authority (*dharmādhikāra*) to be considered a revered preceptor (*ācārya*). A bit further in his discussion on philosophical rationales (*mīmāṃsā*) in his *Sarvasiddhāntarāja* (I.1.55–56), Nityānanda defines his position on divine testimony by saying

> *daivatair munibhir abhyudīritaṃ yat tadeva sakalaṃ samaṃ bhavet |*
> *mānavā 'vyabhicaranty atattvataḥ satyam atra gaṇitaṃ tu yuktimat ||*
>
> *astu vā munivacaḥ pramāṇatā yuktibhiḥ saha tathopalabdhiḥ |*
> *anyathā na katham ādṛtā budhaiḥ sūryaśītakiraṇoparāgatā ||*
>
> Indeed whatever is proclaimed by gods and by the sages, all of that is equal. Men deviate on account of untruth but [the method of] computations is, in this case, the truth with rationales.
>
> May the words of the sages have probative validity, be accompanied by rationales, [and] thus, [lead to] perception. Otherwise, how will the state of the eclipsing of the Sun and the Moon be respected by wise men?

He reiterates his certitude in the words of the gods and the *ṛṣi*s by adding (in I.1.94)

> *yad yad uktam ṛṣibhiḥ devais tat tad atra sakalaṃ saphalaṃ hi |*
> *pūruṣair aviditāgamatattvaiḥ kṣiptam ūharahitaṃ tad asatyam ||*
>
> Whatever is proclaimed by the sages and the gods, all of that, in this case, is indeed fruitful. What is added by men on account of not knowing the truths of the traditional doctrines [and] what is deprived of examination, that is false.

It is, therefore, the rectitude (*samatā*), propitiousness (*saphalatva*), and probative potential (*pramāṇatā*) of divine revelation that makes it true (*satya*). In contrast, any additions by men who are ignorant of the true principles of traditional doctrines (*āgamatattva*s), as well as those additions that are devoid of critical deliberation (*ūharahita*), all of these are veritably untrue (*asatya*).

Interestingly, Nīlakaṇṭha Somayājī, in his *Jyotirmīmāṃsā* (ca. 1504, I.2), offers what is, perhaps, the most rational view on revelation: *granthakaraṇe devatāprasādaḥ mativaimalyahetuḥ na sākṣād upadeśaḥ* 'in composing [one's] text, divine grace is the reason for clarity of thought; not [for providing] manifest instructions'. According to Nīlakaṇṭha, receiving the favour of the gods (*devatā-prasāda*) is revelatory: it offers perspicuity of thought and not a divine dictation, and, accordingly, enables the author's own work to be considered as credible testimony (*āptavacana*) for successive generations of learners. Nīlakaṇṭha makes this argument in critique of the view that Brahmā revealed astronomy to Āryabhaṭa I (founder of the *Āryapakṣa*) having been pleased by Āryabhaṭa's religious austerity (*tapas*) (see, e.g., K. V. Sarma 1977, pp. 2–3).

1.2.3.2 *Predictive and observational prowess*

The power to predict celestial motions accurately was also an important criterion in determining the validity of a source in Sanskrit *jyoiḥśāstra*. Many Sanskrit authors recognised Islamicate astronomy for its power to predict celestial phenomenon precisely. For example, Gaṇeśa Daivajña (fl. ca. 1550–1600), in his *Tājīkabhuṣaṇa* (I.4), encouraged the use of the Tataric science (*tārtīyikaṃ śāstraṃ*) in Sanskrit astrology despite its origins among the Brahmin-hating Turks (*brahmadveṣi-turuṣka*), and justified it by the analogy of appreciating a lotus even if grows in dirt (Gansten 2020, pp. 84–85). Nīlakaṇṭha Somayājī goes further by emphasising the importance of observational concordance, in his *Jyotirmīmāṃsā* (I.4):

> *pañcasiddhāntās tāvat kvacitkale pramāṇam eva ity avagantyam* | *api ca yaḥ siddhānto darśanāvisaṃvādī bhavati so 'nveṣaṇīya* | *darśanasaṃvādaś ca tadānīn taiḥ parīkṣakair grahaṇādau vijñātavyaḥ* | *ye punar anyathā prāktana siddhāntasya bhede sati yantraiḥ parīkṣya grahāṇāṃ bhagaṇādisaṃkhyāṃ jñātvā abhinavasiddhāntaḥ praṇeya ityarthāt* | *tat ta iha loke 'hasanīyāḥ paraloke 'daṇḍanīyāś ca iti* |
>
> The five *siddhānta*s [i.e., the ones described in Varāhamihira's *Pañcasiddhāntikā*] were indeed valid means of knowledge up until a certain point in time, this should be known. Moreover, the *siddhānta* that agrees with observation is [the one] to be desired. And the agreement with observation should be inspected by the examiners at the time of beginning of eclipses. Again, what is different [between observation and theory], evident in the schism in an ancient *siddhānta*, having examined by instruments [and] after having known the number of revolutions of the planets, a modern *siddhānta* should be composed on account of that. Nobody will be ridiculed in this world nor punished in the next [for doing that].

Among the more philosophical astronomers, Bhāskara II's commentator Nṛsiṃha Daivajña, in his commentary *Vāsanāvārttika* on the *Siddhāntaśiromaṇi* (I.1.*bhagaṇādhyāya*.1–6), discusses the value of direct perception (*pratyakṣa-upalabdhi*) in accepting a doctrine that teaches planetary motions (*graha-gati-pratipādaka-śātra*) as probative (*prāmāṇya*). For Nṛsiṃha, the cause (*kāraṇa*) of this perception may be unreal (*atattvika*) as they arise from human reasoning (*puruṣa-buddhi*); however, the effect (*phala*) of this perception is faultless due to the very non-existence of faults (*doṣa-abhāva*) in any effect. Faults lie in the human reasoning that leads to false notions (*vikalpa*s) about the cause, just as seeing the individual soul (*jīva*) separate from God (*iśvara*) is false (*mithyā*) in Advaita Vedānta.[38]

1.2.3.3 Appeal to rationales

For some Sanskrit astronomers, particularly those following Mādhava of Saṅgamagrāma (ca. 1340–1425) in the Kerala (Niḷā) school of mathematics, the continuity of tradition became closely associated with its contemporaneity. Nīlakaṇṭha Somayājī, in his *Jyotirmīmāṃsā* (I.3), quotes from the *Tantravārttika* (I.3.2) of Kumārila Bhaṭṭa, a seventh-century exegesis of Jaimini's *Mīmāṃsāsūtra*, to emphasise the role of tradition (*saṃpradāya*) and inference (*anumāna*). According to Nīlakaṇṭha

> *'jyotiśāstre 'pi yugaparivṛttiparimāṇadvāreṇa candrādityādigativibhagena tithinakṣatrajñānamavicchinnasaṃpradāyagaṇitānumānamūlam' iti vārttikakāro 'pi grahagatijñānam anumanenāha* | (*kumārilabhaṭṭaḥ, tantravārttikam*, 1.3.2) |
>
> Even in the science of astronomy, the computation of *tithi*s and *nakṣatra*s by means of the motion of the Sun and the Moon, which is determined through the number of their revolutions in a *yuga*, is based on the continuity of tradition and deduction.
>
> (Kumārila Bhaṭṭa, *Tantravārttika*, 1.3.2)
> (Subbarayappa and Sarma 1985, pp. 57–58)[39]

Other Siddhāntic authors have also spoken about provability or demonstrability (*upapattitva*) as a standard for validating astronomical computations; see, e.g., Bhāskara II's statement in his auto-commentary *Vāsanābhāṣya* on his *Siddhāntaśiromaṇi* (I.2.1–6) in endnote 11 on page 48.

1.2.3.4 Epistemic pluralism

Nityānanda professes a pluralistic epistemology where authoritative speech (*āptavāc*), appeal to antiquity (*prācīna-matāvalambana*), concordance with observations (*dṛktultyatva*), and rational explanations (*yuktārtha-vyākhyā*s) are all regarded as valid epistemic means (*pramāṇa*s). In his view, different epistemic criteria should be applied appositely to assess the validity of a particular position (or proposition). Accordingly, in his *Sarvasiddhāntarāja* (I.14–15), he offers three distinct and individual justifications for accepting the three *siddhānta*s (i.e., the *Romakasiddhānta*, the *Sūryasiddhānta*, and the *Brāhmasphuṭasiddhānta*):

> *dṛṣṭvā romakasiddhāntaṃ sauraṃ ca brāhmaguptakaṃ* |
> *pṛthak spaṣṭān grahāñ jñātvā siddhāntaṃ nirmame sphuṭam* ||
>
> *romakoditakhacāracāturī dṛktulāṃ vrajati sarvathā sadā* |
> *sauratantram iha vedavid vidur jiṣṇujoktam api yuktayuktiyuk* ||
>
> Having consulted the *Romakasiddhānta*, the *Sūryasiddhānta* and [the *siddhānta* of] Brāhmagupta individually, [and] having known the true [positions of the] planets, I composed the true *siddhānta*.

> The motion of the heavens described by Romaka always agrees with observation in every respect. Men versed in the Vedas recognised [their doctrine] in this treatise of the Sun [i.e., the *Sūryasiddhānta*], [and] the very words of Jiṣṇuja [i.e., the *Brāhmasphuṭasiddhānta*] are endowed with appropriate rationales.

In many ways, the *Sarvasiddhāntarāja* is a treatise that breaks away from doctrinal partisanship (*saiddhāntika-pākṣatā*) in favour of syncretism (*samanvayavāda*). By discussing Islamicate astronomical parameters and computations in the *Sarvasiddhāntarāja*, and occasionally doing so with a completely novel vocabulary, Nityānanda brings the science of the *yavana*s to meet the traditions of Sanskrit *jyotiḥśāstra*. Neat the beginning of the text, in I.9–10, he recognises the novelty (*nutanatva*) of his composition, and then goes on to state what he thinks a *siddhānta* is meant to be:

> *ihānekaiś cakre svakṛtir akṛtārtheva kṛtibhīḥ*
> *purā pāramparyād anavaracanaiś cāruvacanaiḥ* |
> *mamāpi grantho 'yaṃ navanavasuyuktyuktisahito*
> *vilokyo dhīmadbhiḥ kutukam iva siddhāntakuśalaiḥ* ||
>
> *siddhāntaityanugatārthapadaprayogād*
> *yad vastu sūkṣmataram asti tadeva siddham* |
> *nānyac ca golagaṇitadvayayuktihīnaṃ*
> *kiṃvopalabdhirahitaṃ sudhiyeti cintyam* ||
>
> In this regard, up until now, the works authored by many experts are just unaccomplished with no novel compositions [and merely] beautiful words following tradition. Although this book of mine is composed with completely new rationales and words, [it] will be seen by learned men competent in the doctrines with a little curiosity.
>
> Because the use of the word *siddhānta*, the [etymological] meaning of which is pertinent, only that topic which is most precise is to be considered as established by a learned man, not anything else which is devoid of the rationales of both spheres and computations or devoid of perception.

According to his statements, a genuine astronomical *siddhānta* should include only those methods that yield the most precise (*sūkṣmatara*) results, following the very etymology of the word *siddhānta*, the 'established end'. If traditional methods are lacking in the rationales (*yukti-hīna*) of spheres (*gola*) and computations (*gaṇita*) or are perceptively deficient (*upalabdhi-rahita*), a mere repetition of these methods in one's work does not merit the title *siddhānta*. Such irrational works should be decried by learned men even if they pander to tradition with beautiful words.

1.3 The *golādhyāya* in Nityānanda's *Sarvasiddhāntarāja*

The *golādhyāya* 'chapter on spheres' in Nityānanda's *Sarvasiddhāntarāja* describes the terrestrial sphere (*bhūgola*) and three different orientations of the celestial sphere (*bhagola*, *khagola*, and *dṛggola*). The configuration of the great circles on these spheres forms the geometrical basis for the computational methods described in the *gaṇitādhyāya* 'chapter on computations'. Most Siddhāntic authors have discussed spheres (*gola*) as separate sections or chapters in their own works, and in particular, authors from the Kerala (Niḷā) school of mathematics have discussed spheres in separate ancillary texts (*tantra*s) to their technical treatises; see, Table 1.4.[40]

The list of topics in the *golādhyāya*s of most *siddhānta*s vary, albeit only slightly. The enumerated list below indicates the types of topics discussed in Siddhāntic *golādhyāya*s. (This list is drawn from Lalla's

Table 1.4 List of Siddhāntic and Tāntric works discussing spheres (*gola*)

Title	*Work*
golapāda	*Āryabhaṭīya* of Āryabhaṭa I (499)
gola	*Brāhmasphuṭasiddhānta* of Brahmagupta (628)
bhūgolādhyāya	*Sūryasiddhānata* unknown authorship (800)
golābandhādhikāra	*Śiṣyadhīvṛddhidatantra* of Lalla (ca. eight/ninth century)
golādhyāya	*Vaṭeśvarasiddhānta* of Vaṭeśvara (904)
golādhyāya	*Mahāsiddhānta* of Āryabhaṭa II (ca. 950–1000)
golavāsanā and *golavarṇana*	*Siddhāntaśekhara* of Śrīpati (ca. mid eleventh century)
golādhyāya	*Siddhāntaśiromaṇi* of Bhāskara II (1150)
bhāṣya	*Siddhāntadīpikā* of Parameśvara (1432)[a]
bhāṣya	*Goladīpikā* I of Parameśvara (1443)[b]
bhāṣya	*Goladīpikā* II of Parameśvara (ca. 1450)
sāragrantha	*Golasāra* of Nīlakaṇṭha Somayājī (ca. 1500)
golādhyāya	*Siddhāntasundara* of Jñanarāja (1503)
golādhyāya	*Sarvasiddhāntarāja* of Nityānanda (1639)
avanigolaja	*Siddhāntasarvabhauma* of Munīśvara Viśvarūpa (1646)
gola	*Siddhāntasamrāṭ* of Jagannātha (1732)
gola	*Paramasiddhānta* of Premavallabha (1882)
golādhikāra	*Siddhāntadarpaṇa* of Sāmanta Candraśekhara (1899)

a a super-commentary on Govindasvāmin's *Mahābhāskarīyabhāṣya* of Bhaskara I.

b includes the author's self-commentary (*vivṛti*).