Flemish, Ghent-Bruges School
Illuminated Manuscript Page with Naturalistic Border of Birds, Insects, and Flowers, 1500–1510
Tempera and gold on vellum
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The Physical Spell of Gregorian Chant

The dove alighted on Saint Gregory's shoulder and sang secrets into his ear. It was as if the soft reverberations, sounding within a cathedral at the singer's pause, evoked the Holy Ghost's whisper. In this sense, Gregorian chant clearly communicates a religious meditation. Even in the eighth century, when Gregorian chant first emerged, Christians heard the music as stemming from an authentic tradition (Palisca 33). It pierces the body with its eerie simplicity, seeming utterly natural. The curving vocal line gently hovers about a tonal center and the smooth motion of the cadence feels more like a sigh than an emphatic conclusion characteristic of Western diatonic harmony. In this sense, the drifting dove is a perfect metaphor for Gregorian chant: it is pure, fluid, and spiritually moving. From the eighth century through the Renaissance, Gregorian chant was heard as the echo of God's perfection and order lingering in the corporeal world. Chant emerged not merely as a representation of divinity, but as an actual embodiment of divinity. Rooted in Pythagorean conceptions of harmony and balance, Gregorian chant grew from an intuitive awareness of how the ear interprets sound. The music was deemed capable of salvation through its very physical effect on the listener. In this way, Gregorian chant is a beautiful homage to the logical and powerful nature of physics and music.

Gregorian chant strictly adheres to Pythagorean theories of intervallic relationships. The Ancient Greeks divided their writings about music into two main categories. The first comprised systematic analysis and rules of music composition while the second addressed the philosophical nature of music, its effect on behavior, its function within society, and its place in the cosmos (15). Pythagoras, who lived in the sixth century BCE, discovered that a string divided into segments of small-number ratios would emit harmonious tones when plucked. This fit his belief that the beauty of the universe derived from simple proportions. An octave was found to have a ratio of 2:1, a perfect fifth possessed the ratio 3:2, and a perfect fourth contained the ratio 4:3 (Selby, lecture # 16). Music was considered to embody the concept of harmo-

nia: a pure, structured universe where the parts were synthesized into an orderly whole. Plato also spoke of the "harmony of the spheres," music too evanescent for mortal ears that sounded as the planets revolved. This insight surprisingly foreshadows the discovery that a harmonic oscillator, such as a column of air or a string, produces practically inaudible overtones that are integer multiples of the perceived pitch (Rossing 64). This set of relationships is called the harmonic series and begins with an ascent of Pythagoras's octave, a subsequent addition of a perfect fifth, and a further ascent of a perfect fourth to arrive at the first three overtones. The patterns of physics, music, and mathematics align.

In the second category of musical analysis, the Ancient Greeks expressed their belief that music could affect behavior, setting a model for Christian leaders who wanted chant to communicate religious ideals (Palisca 15). Harmony in music could inspire harmony in individuals. Aristotle even specified types of scales, called modes, according to the responses they could provoke. These modes were all diatonic, meaning that they incorporated five whole tones and two semitones in varying orders (Laitz 8). Christian leaders later interpreted these delineations as an outline for what would become the eight Church modes (Palisca 15).

Despite the fact that there were many disparate versions of chant spread across Europe, each a part of a distinct liturgy and ceremonious rite, all chant music embraced the diatonic scale and tuning system outlined by the Ancient Greeks (29). Attributing the origin of Gregorian chant to Pope Gregory the Great (r. 590–604) was actually a mistake made by the English, who worshiped Saint Gregory as the founder of their church (Palisca 32). Chant did not formally begin until the late seventh century, with the foundation of an elite choral group called the Schola Cantorum who sang only for the Pope's services in Rome. By the eighth century, melodies began to be standardized and became an integral component of Christian services. Extreme tension between the Eastern Byzantine Empire and the Western Roman Catholic Church made the unity of Christian practices all the more pressing. As a means of combating the Byzantine Empire's claim to spiritual and political leadership, Pope Stephen II worked to institute a formal Roman liturgy, a set procedure of worship. Between 752 and 754, he brought the Schola Cantorum on a trip to the newly established Frankish Kingdom with the hopes of grounding their musical rituals in an unstable land

(31). As a result of the visit, Frankish King Pepin the Short ordered that his people worship according to the Pope's liturgy (Crocker 72). With the help of Roman leaders, Frankish royalty essentially codified the disparate strands of church music into Gregorian chant and assigned the pieces to different services throughout the year, an establishment that did not change until the sixteenth century (Hornby 4). The Franks have also been credited for inventing musical notation and fitting Gregorian chant into the Greek system of eight modes (Cirillo 28).

When defining the parameters of chant, Christian leaders carefully selected from the musical traditions around them, so carefully that they essentially avoided all distinguishing aspects of music such as rhythm, timbre, and harmony (Crocker 69). This is only true on the surface, however, since chant music has a distinct sound, a quality that penetrates the listener and clears the mind. Choirs were meant to rejoice in pure diatonic pitch relationships. A typical vocal chant phrase takes the shape of an arch: the melody begins low, rises and lingers on the reciting pitch, and then descends with the suggestion of a cadence. The reciting pitch is a repetition or, rather, a meditation on one note for an extended period of time. There are no embellishments, for this would interfere with the expression of the religious texts. The melodies mirror the text's structure; accented words are set to higher pitches for an equivalent musical emphasis (Palisca 57). The ordering of notes is not significant, so long as the pitches move primarily by whole or half steps, adhering to the construction of the diatonic scale. Step-wise motion gives the chant an effortless, natural quality of a floating ghost. The Church felt this ethereal voice would be polluted by the presence of other instruments. According to Fourier analysis each instrument possesses distinct timbres due to its unique recipe of harmonic intensities (Rossing 136). The recipe enables the listener to identify the instrument. Since instruments create contrasting timbres, the Church believed they would poison direct expression. Rhythm was similarly considered too carnal and the absence of meter aided chant in its suspenseful nature.

The *reciting pitch* is the climax of the chant. Sharply defined in an expanse of twisting tones, the reciting pitch carries the spiritual message and seeks to penetrate the worshipers. As equally spaced iterations of the same frequency enter the ear, the listener may feel that the music is actually vibrating in his body. In this sense, the reciting pitch utilizes the power of the resonance phenomenon. Resonance occurs when a

driven frequency is equal to its natural oscillating frequency. In other words, all vibrating systems have a natural frequency at which they prefer to move, and if they are compelled to vibrate at this frequency by an external force, they will resonate (Selby, lecture # 6). The reciting pitch intentionally throbs with a steady pulse, re-sounding in the ear at a constant rate and filling the space until it feels as if the building itself is producing the tone (Crocker 26). In this way, the reciting pitch hopes to make the worshipers unite and resonate with the word of God, with the music of physical perfection.

Gregorian chant was usually sung by the entire congregation and the melodies were always performed in unison. The choir had to sing "'as if with one voice,' *quasi una voce*" (25). "As if" suggests that the Church understood the discrepancy in tone purity that would result when a group sang together. There would be an apparent roughness to the sound. Since it is not possible for all the members of a choir to sing at exactly the same pitch, slight differences in frequencies will create an interference effect. Beats occur when frequencies with minor differences in wavelength move in and out of step with one another. The ear detects a single tone with a pulsing quality, one that vibrates at the average of the original frequencies (Selby, lecture # 15). Although this impure sound cannot be prevented in a choir of untrained singers, it beautifully captures the longing for unity that is so much a part of Christian doctrine. The tone itself symbolizes the Christian paradox of men seeking to be "one in Christ" (Crocker 25). The roughness reminds the listener of his imperfection, his mortality, and fuels the desire to unite with the Church. Whether this was the exact motive of chant composers or a product of physical intuition is of course unclear; yet it certainly seems that chant incorporates physics in an extraordinarily moving way.

Despite the slightly rough timbre generated by the cluster of frequencies, chant melodies are able to resonate clearly throughout cathedrals. Sound waves reflect off the walls and ceilings as well as diffract around structural edges. The waves actually bend around obstacles, enabling them to carry energy across a larger area (Selby, lecture # 5). The rectangular shape of early churches sparks lateral reflections, and the large size forces the sound to travel a long distance. Reverberation, the sensation that a sound persists even after emission has ended, occurs when the structures of the room do not absorb the sound but instead reflect the sound waves to a great degree (Cirillo 41). Roman-

esque and Gothic churches are made primarily of stone and filled with wooden pews, characterizing the space with low acoustic absorption. The fact that there are few absorptive materials means that the sound of the chant echoes throughout the church, often reverberating with a delay of three or four seconds (Crocker 26). The overtones, which build at different rates, are exquisitely highlighted in this environment as their distinct wavelengths bounce off the walls, overlap, and slowly decay (Cirillo 4).

Because of the church architecture, words are actually more easily understood when sung. Again it seems the physical necessity provoked the music. The strong reverberations approaching from all directions give the sense that the congregation is completely immersed in the sound. This phenomenon, called listener envelopment, derives from a large apparent source width, an impression that the sound source is somehow broader compared to its actual size. Completely surrounded by the echoes, the congregation is essentially responsible from an acoustic standpoint for absorbing the sound. This means that the church needed to be filled in order to strike a balance between reverberation and clarity (48).

The structure of the cathedrals mirrors chant in its accordance with Pythagorean ideals. By the year 800, European architects incorporated symmetrical and modular designs into their Gothic churches. Arches and other architectural features were constructed so that the largest surfaces were always exact multiples of the smallest units (Crocker 26). This concept exactly parallels the structure of the intoned sound wave where the different modes of vibration are integer multiples of a fundamental. When boys sing the melody an octave higher than the men, they are reinforcing the second harmonic, emphasizing the importance of simple ratios of sound. A beautiful symmetry exists between the simple movement of the tone through balanced diatonic relationships, the proportions and reverberations of the space, and the calm induced in the worshiper who absorbs such physical harmony.

Although Gregorian chant feels melodically simplistic, it actually stems from a complex system of Church modes. Essentially, the Church modes consist of the same tones found in the diatonic scale of C major; yet they are organized in such a way that there is a different starting pitch for each mode. The concept of dividing the octave into distinct arrangements of whole and half steps stems from the Greek writer Cleonides in the second or third century (Palisca 18). Cleonides

discovered that the perfect fourth and the perfect fifth could break into tones (T) and semitones (S) (whole steps and half steps) in a limited number of ways. He called these arrangements species. Below is a list of species for the perfect fourth, the perfect fifth, and their corresponding pitches:

The Three Species of the Perfect Fourth:

S – T – T (b, c, d, e)
T – T – S (c, d, e, f)
T – S – T (d, e, f, g)

The Four Species of the Perfect Fifth:

S – T – T – T (e, f, g, a, b)
T – T – T – S (f, g, a, b, c)
T – T – S – T (g, a, b, c, d)
T – S – T – T (a, b, c, d, e)

Table 1: Components of Octave Species (Palisca 18)

Since multiplying the ratio of a fourth (4:3) by the ratio of a fifth (3:2) gives the ratio of an octave (2:1), it is clear that the species of a fifth can be combined with the species of a fourth to get seven different octave species. Each species will begin with a different pitch of the C major scale and will therefore have a distinct pattern of whole tones and semitones. These scales developed into the eight Church modes that dominate Gregorian chant. The eight modes are as follows:

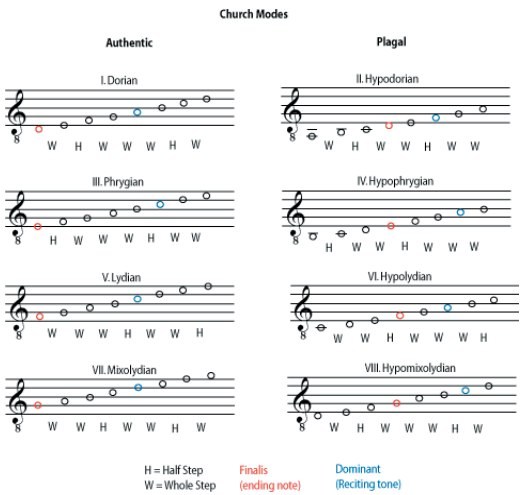

Figure 1: Church Modes (http://cnx.org/content/m11633/1.5)

As Figure 1 shows, each mode begins with a different starting pitch. The mode has a *final, range*, and *tenor* (which is marked in blue on the image above). The *final* is the main note around which the melody revolves. It is not the tonic in the classical sense, since there is no intentional conception of triadic harmony within these systems, but it essentially functions as a kind of "tonal center." The modes are still tonal due to their ratios of whole and half steps. In this manner, they can still provide the ear with a sense of a cadence, or a conclusion, as the listener begins to intuit the consonant pitch relationships.

Each odd-numbered mode shares a final with a corresponding even-numbered mode. The two sets of modes differ in *range*. Authentic modes begin a step below the final and span about an octave. Alternatively, plagal modes begin either a fourth or a fifth below the final and move to a sixth above (Palisca 44). Since Christians were attuned to the nuances of these modes, they heard a great difference between a cadence in the middle of the octave and a cadence near the ends of the range. The *tenor*, which is another word for the reciting pitch, differs among the modes. In general, rules dictated that the tenor of an authentic mode reside a fifth above the final and that a plagal mode must have its tenor a third below the tenor of its corresponding authentic mode. The main exception occurred when the tenor fell on the note B, in which case it was moved up to C (45). Only one chromaticism was allowed; the note B flat. Diminishing the B was integral to creating a mode revolving around F for the relationship between F and B flat is a perfect fourth while the relationship between F and B was considered preposterously diabolical.

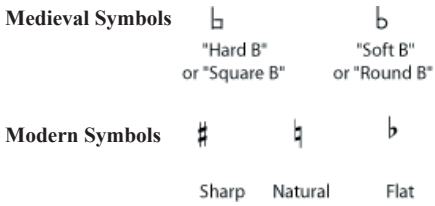

Figure 2: Modern symbols for "natural" and "flat" stem from the medieval notation of the only chromaticisms allowed in chant music. (http://cnx.org/content/m11633/1.5)

The composers of Gregorian chant and the leaders of the Church were probably not thinking of the laws of physics when they constructed

these scales. However, they must have intuited certain physical and logical phenomenon in their quest for absolute symmetry (Schmidt-Jones). Just as modern notions of physics can now shed light on musical practices of the eighth century, polyphonic tonal theory, which grew directly from chant music, can lend great understanding to the construction of Gregorian chant. The church was not thinking of Cleonides's findings when they developed the Church modes; this was a connection made by later medieval music theorists (Palisca 45). The similarity is not coincidental; it is another sign of the chant's innate connection with logical structures found in music and physics. Composers of polyphonic music, music in which there exist many independent, contrapuntal vocal lines, analyzed chant melodies in order to use them as a *cantus firmus*, a term introduced around 1270 referring to a pre-existing melody incorporated into a new work and dictating the harmonic motion of a polyphonic piece (107). Through examining Gregorian chant, theorists outlined the Church's strict rules that meant to evoke physical perfection. These guidelines, which were essentially codified by the composer Palestrina, stipulated that the phrase should take the form of an arch, beginning and ending on the final pitch. The final had to be approached by steps. The entire melody should utilize the pleasing simplicity of step-wise motion and only occasionally incorporate skips of a third. Pitches that ascend for three or four notes in a row must switch direction in order to maintain a balanced phrase. Notes other than the tenor should not be reiterated and the intervallic relationships between notes must be consonant (Laitz 59). These restrictions served a double purpose: they adhered to ideals of simplicity and made it much easier for the average choir to sing.

The elimination of dissonant leaps explains why Gregorian chants avoid the note B. The interval between a B and an F is called a tritone and lies directly between a perfect fifth and a perfect fourth. If a B and an F less than an octave apart were played simultaneously, there would be an extreme roughness in the timbre due to the appearance of beats. Even though the difference in frequency between B and F is more than 10 Hz, their fundamental frequencies as well as some of their harmonics lie within what is called the same *critical bandwidth*. Inside the ear, there is a basilar membrane that responds to different frequencies at distinct locations. High frequencies are picked up by hair cells near the oval window while lower frequencies are registered on the opposite end of the membrane. When frequencies entering the ear trigger vibra-

tions of similarly located hair cells, they are said to lie within the same critical bandwidth. Their overlap results in what the ear interprets to be a rough sound, a dissonance (Selby, lecture # 8). With an intuitive awareness of acoustics, composers of Gregorian chant sought to rule out any signs of disorder in favor of ultimate equilibrium.

The purity and balance found in Gregorian chant is perhaps best described by the musical manuscripts themselves. The notation, the representation of the vocal line, reveals how simple and physical the chant really is.

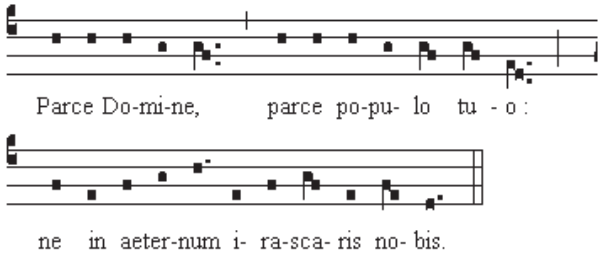

Figure 3: Notation for Parce Domine (http://comp.uark.edu/~rlee/chant.html)

The squares above, called *neumes*, trace the outline of the melody on the musical staff. The top line is middle C and is bracketed by a clef on the left-hand side. Since A is the only repeated note, it is safe to assume that it is the tenor. Two phrases end on the bottom line indicating that D is the final. D is always approached by steps; it always follows the note E. With the tenor found a fifth above the final and with a cadence on D, this melody fits the Dorian mode. The winding nature of the tune is apparent; descending lines are quickly balanced by upward motion. The only references to rhythm are the vertical lines, which mark the end of phrases, and the image of two neumes joined together. This symbol, called the *clivis*, dictates that the linked notes involved should be sung faster than the individual notes (Lee). If a tiny dot follows a *neume*, it should be held for a slightly longer period of time. Each subsequent line and space stands for a different pitch in the diatonic scale. The floating nature of the Chant is clear; it looks as if the *neumes* are slowly drifting across the page. As the melody eases downwards, lifts, and sustains, it takes the listener on a spiritual journey, encouraging the congregation to rise, hinting at the limitations of man, leaving the worshiper in a state of limbo.

Analyzing the purpose of music in church, its place in the cosmos,

and the composer's underlying intentions can make it easy to forget that music at its core is not just an emotional or intellectual exercise. Music is a physical manifestation; it depends on space, time, and the human body with all of its imperfections. What is so moving about Gregorian chant is that while it seeks to emulate pure, divine harmony, its simplicity leaves both the performer and the listener utterly exposed. The listener hears the flaws in tone, senses the pulsing beats, experiences the effects of the room on the sound. The discrepancy between the dove's ideal floating melody and the music produced by the human voice is tangible. Imperfection is everywhere. Saint Gregory's dove only whispered the secrets, and in this sense, they can never be born into the physical world, never heard by mortal ears. The bare voice desperately appeals to the ear, yearns for unity: it pleads for acceptance. As the eerie melody spreads its message, it leaves the congregation vulnerable. The silence after the voice has ceased, the stillness in the room as the echoes fade away, is just as powerful as the music itself. A breath is drawn, the chant is repeated, and the meditation begins. The music calms the body with its purity yet suggests a haunting instability. In this way, Gregorian chant emulates both physical logic and physical inadequacy. As much as this music evokes the movements of God, it is at its heart utterly human.

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