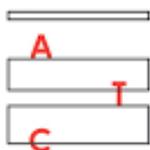


# Descending Equi-heptatonic Circuits

*An experimental composition for Classical-era auloi  
with diagrams and commentary by Barnaby Brown*



Reeds and reproduction by Robin Howell of an aulos  
buried 400–350 BCE in Pydna, northern Greece.



**ACTORS TOURING COMPANY**

EUROPEAN MUSIC ARCHAEOLOGY PROJECT



With the support of the  
Culture Programme of the European Union



Published for the European Music Archaeology Project  
by Barnaby Brown

2018

**Duration:** c. 5 minutes

## CONTENTS

<i>Score</i> Version 2.2 (30 July 2018).....	3
<i>Diagram 1</i> Version 1.2 (27 June 2018).....	6
<i>Diagram 2</i> Version 1.1 (31 May 2018).....	7
<i>Commentary</i> Version 1.1 (4 September 2018) .....	8
<i>Bibliography</i> .....	30

*Updates & open file formats:* DOI [10.6084/m9.figshare.7006208](https://doi.org/10.6084/m9.figshare.7006208)

*Audio, video & discussion:* [doublepipes.info/descending-equiheptatonic-circuits](https://doublepipes.info/descending-equiheptatonic-circuits)

### ***Licence***

These materials are released under the [Creative Commons license CC BY 4.0](https://creativecommons.org/licenses/by/4.0/) to help establish an open culture of data-sharing, collaboration, and distributed testing and development in the field of Very Early music. Suggestions for best practice include:

- in the case of performances, releasing audio or video documentation online and linking reciprocally between this and the development hub for this volume at [doublepipes.info/descending-equiheptatonic-circuits](https://doublepipes.info/descending-equiheptatonic-circuits); and
- in the case of revisions and transformations of the composition or these study materials, providing a summary of the changes you make with explanations in a form that engages performers, giving bar references and citing any ancient evidence or modern scholarship that informs your decisions.

For more on this series of resources and reflections on this emerging discipline, see the ‘Introduction to the EMAP Resources for Euterpe’ in [Volume 1](#).

# Descending Equi-heptatonic Circuits

for Poseidonia/Pydna/Elgin aulos • composed 8–15 March, revised 18 May 2018

This composition is a training ground for producing pure intervals between the High and Low pipes. It reconstructs an auletic tonal system that supports extensive modulation: an elastic network of seven tetrachords pitched roughly a seventh-octave apart (see Diagram 1). The pitch offsets (-43, -14, etc.) should not be adhered to: the right pitch is the one at which pure fifths and fourths require the least embouchure adjustment. The hole boring of these auloi means that all fifths must be stretched and all fourths narrowed — do this by relaxing the embouchure and fractionally pulling out whichever pipe needs to be flattened. The written pitch corresponds to the Pydna aulos; the Poseidonia sounds about a semitone higher, the Elgin about a tone lower. The musical meaning of the terms Dorian, Aeolian, etc. changed over time; the usage here is a hypothesis for auletes around 500 BCE and bears no relation to the usage of medieval or modern musicians (see Diagram 2). For further information, see the Commentary.

## Hypodochē (summons, trumpet fanfare)

Barnaby Brown (b. 1973)

6  
H-0  
L-0  
-43 Dorian

9  
-14 Aeolian (Slack Lydian)  
+14 Iastian (Hypophrygian)

11  
+43 Phrygian

## A Spondeion (libation to the gods, dignified, disciplined)

15  
-43 Dorian  
-14 Aeolian  
+14 Iastian  
+43 Phrygian  
-43 Dorian

18  
-14 Aeolian  
+14 Iastian  
+43 Phrygian  
-43 Dorian

21  
-29  
-14 Aeolian  
0

39

+14 Iastian +29 Phrygian +43

**B Harmonia** (refined, educated, noble)

45

-43 Dorian -29 Mixolydian

52

-14 Aeolian (Slack Lydian) 0 (Tense) Lydian

59

+14 Iastian +29 Phrygian

66

+43

73

Locrian (New Hypodorian)

**C Diatonos** (popular, common, successful)

77

-43 Dorian -29 Mixolydian -14 Aeolian

83

0 Lydian +14 Iastian

89

+29

93

+43 Locrian

**D** Chrōma (sweet, licentious, emotional)

98

f Phrygian mf mp p

105

pp -43 Dorian -29

114

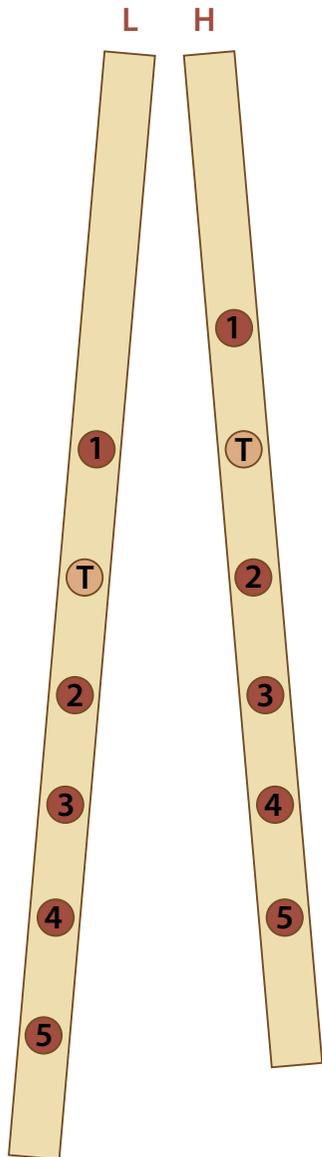
-14 Aeolian 0

123

+14 Iastian +29 Phrygian

131

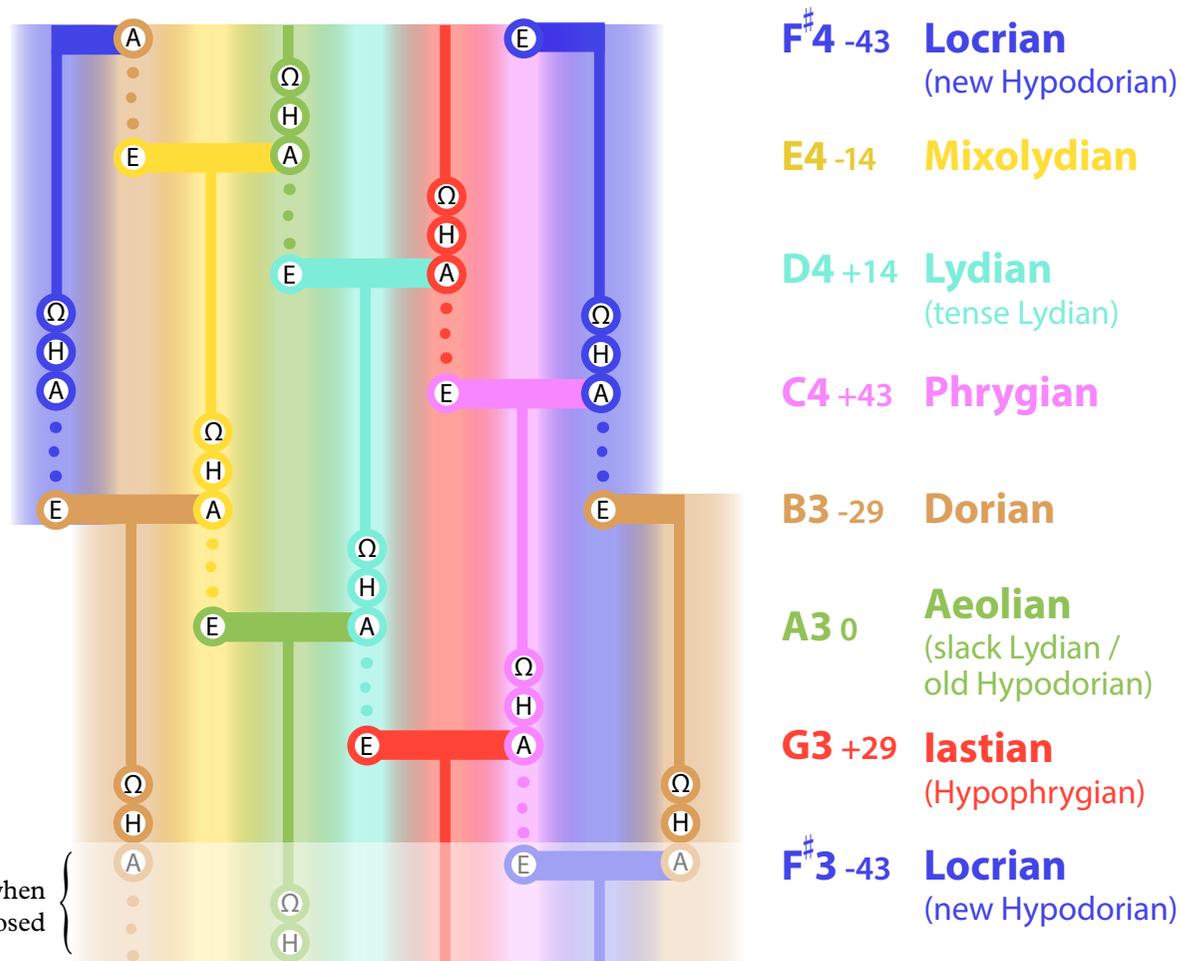
+43



# Seven equidistant enharmonic tetrachords

Barnaby Brown, *Descending Equi-heptatonic Circuits*. **Diagram 1**

Version 1.2 (27 June 2018) | DOI: 10.6084/m9.figshare.7006208  
 EMAP Resources for Euterpe 2 | [emaproject.eu/events/euterpe/resources](http://emaproject.eu/events/euterpe/resources)  
 Updates & discussion: [doublepipes.info/descending-equiheptatonic-circuits](http://doublepipes.info/descending-equiheptatonic-circuits)



This network of T-junctions is a hypothetical model of how aulos players modulated in the *nomos trimelēs*, the dithyramb and drama in the period c. 550–400 BCE, i.e. between Sakadas of Argos and Pronomus of Thebes. At each T-junction, fourth-century Greek musicians called the tetrachord to the right ‘conjunct’ (*synēmmenon*, a fourth higher) and the tetrachord to the left ‘disjunct’ (*diezeugmenon*, a fifth higher); the tones of disjunction are represented by three dots.

In the Roman period, the vowels alpha (A), eta (H), omega (Ω) and epsilon (E) identified a note’s position in the tetrachord, like *Do Re Mi Fa* in a movable-Do system. This was in a diatonic environment; their use in the enharmonic environment of the Classical period is hypothetical.

The pitches given here are approximately those of the Pydna aulos (the Poseidonia is about a semitone higher, the Elgin about a tone lower). The offsets in cents show the discrepancy between an equidistant 7-tone system and the equidistant 12-tone system of Aristoxenus and staff notation. Only the former is compatible with the hole boring of Classical-era finds. For pure intervals, all fifths must be widened and all fourths narrowed by roughly 16 cents. This requirement for pitch adjustment on every note excludes lyres from this tonal system.

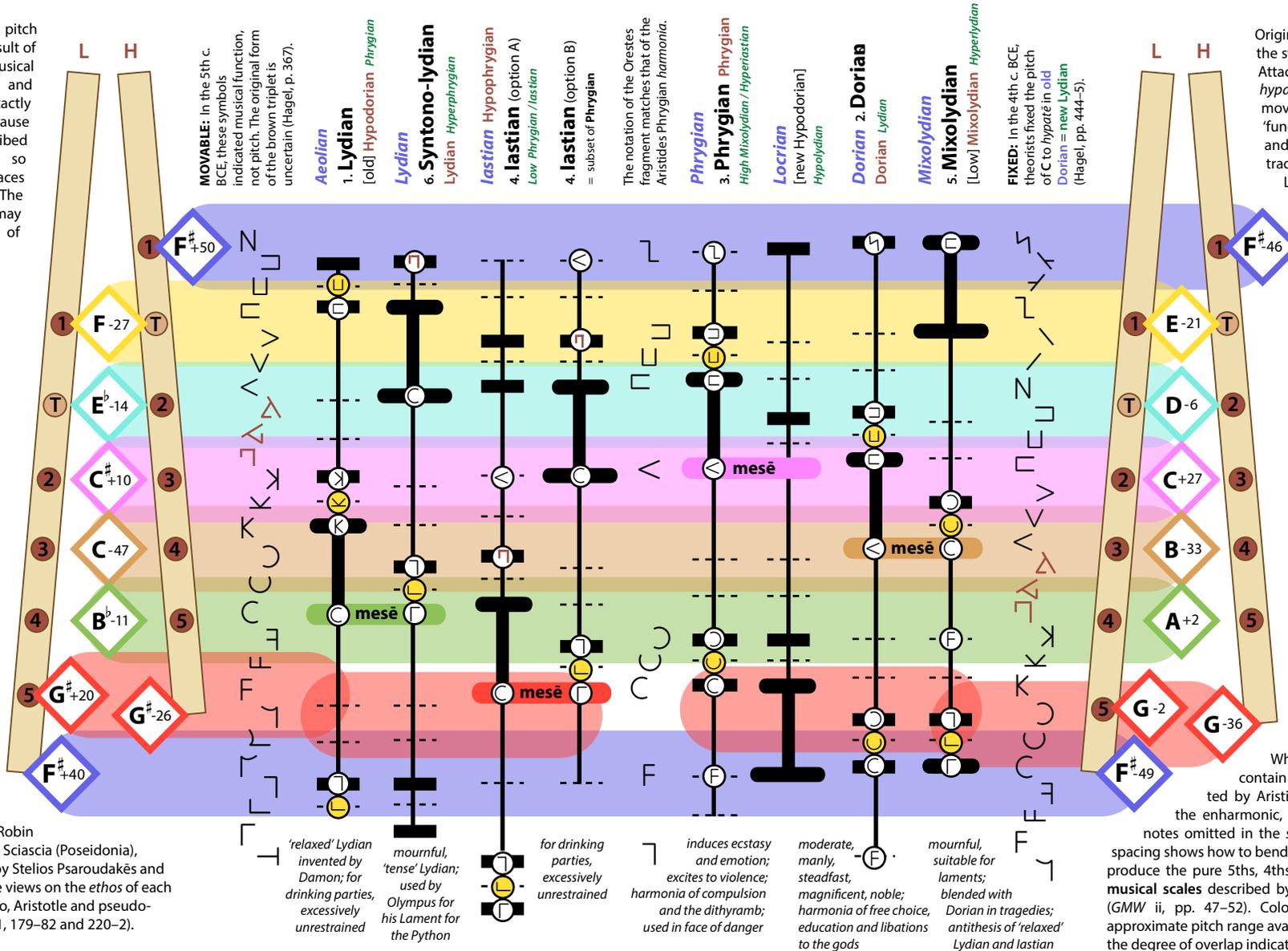
**Key to an evolving nomenclature:** **Early 5th-c. names transmitted by Heraclides et al.** experimentally attached to a tonal system compatible with the Poseidonia and Pydna auloi (see Diagram 1) | **Late 5th-c. names transmitted by Aristides Quintilianus** of 6 scales corresponding to the *harmoniai* of Plato's *Republic* (c. 380 BCE) | **Early 4th-c. names used by aulos makers** for a system of 7 *tonoi* in which Dorian and Phrygian are spaced a tone apart, the other *tonoi* a 3/4-tone apart | **Late 4th-c. names used by Aristoxenus** for a system of 13 *tonoi* all spaced a semitone apart. *Selected reading:* Stefan Hagel, *Ancient Greek Music* (2009), pp. 375–7 and 430–4; and Andrew Barker, *Greek Musical Writings (GMW)* i, pp. 163–9, 281–4; ii, pp. 153–4, 419–22.

# The *harmoniai* of Plato's *Republic*: one of many possible auletic solutions

Scholars agree that the pitch drop of Dorian was the result of paradigm shift in musical behaviour between 450 and 350 BCE. What exactly changed is uncertain because the 12-tone system described by Aristoxenus proved so successful that few traces remain of its precursors. The best evidence for them may be the hole boring of 5th-century auloi.

**Poseidonia aulos**  
buried c. 480 BCE at Paestum, Italy  
found 1969

This diagram modifies Hagel's Diagram 11 (p. 42). Modifications were prompted by experiments playing reproductions by Robin Howell (Pydna) and Marco Sciascia (Poseidonia), based on measurements by Stelios Psaroudakēs and using reeds by Howell. The views on the *ethos* of each *harmonia* are those of Plato, Aristotle and pseudo-Plutarch (*GMW* i, pp. 130–1, 179–82 and 220–2).



**Pydna aulos**  
buried 400–350 BCE at Pydna, Greece  
found 1996

Originally, the meaning of the symbol C was functional. Attached to either *mesē* or *hypatē*, its pitch was movable. Hagel calls this 'functional notation' (p. 383) and notes that 'we find traces of this 'transposing Lydian' approach well into late antiquity, especially in instrumental scores' (p. 445).

Here the *harmoniai* are paired in four 'Unmodulating Systems,' each with its *mesē* on a different fingering. White and gold circles contain the notation transmitted by Aristides. Dotted lines show the enharmonic, chromatic and diatonic notes omitted in the *spondeion* scale. Vertical spacing shows how to bend the instrument scale to produce the pure 5ths, 4ths and major 3rds of the musical scales described by Plato's friend Archytas (*GMW* ii, pp. 47–52). Coloured bands show the approximate pitch range available on each fingering; the degree of overlap indicates how far the hole-boring is from equi-heptatonic tuning. The bands are centred on the median pitches estimated in diamonds (Hagel, in preparation). On any pipe, one of the two lowest pitch bands is unavailable; which, depends on whether hole 5 is open or closed.

## Barnaby Brown, *Descending Equi-heptatonic Circuits. Diagram 2*

## Commentary

*For general information about this series, see the 'Introduction to the EMAP Resources for Euterpe' in Volume 1.*

**T**HIS EXPERIMENTAL composition tests a new hypothesis for the auletic art of modulation. The original intention was to compose with an understanding of ancient Greek music theory, taking generations of scholarly endeavour into account. This proved to some extent impossible, not because the literature is difficult (which it is) but because the archaeological finds of auloi disrupt established ideas concerning musical developments in the Classical period – nominally 510–323 BCE. This is hardly surprising. Brilliant guesswork has been built on literary evidence that is sparse and often significantly later in date; the scholarship is formidable. Trials making and playing critical reproductions of Classical-era finds, on the other hand, are still in their infancy; *Descending Equiheptatonic Circuits* is the first experiment to be reported in any detail.

In this Commentary, I attempt a coherent synthesis of literary and material evidence, focusing on the tonal system of aulos-based music in the sixth and fifth centuries BCE. It is aimed at an interdisciplinary audience that includes aulos learners, composers, music directors, Classicists and musicologists. These groups have different needs and very different levels of understanding in each other's fields; I beg the reader's patience with my attempts to accommodate such a diverse audience. Presenting a case for this hypothesis requires a broad survey of evidence that will, I hope, interest players and composers. It introduces the technical aspects of Classical Greek music that are most relevant to performers, ignoring all developments after about 380 BCE. One vital point to clarify at the outset is that modern preconceptions regarding the musical meaning of the terms 'enharmonic', 'Dorian', 'Phrygian', etc. must be

discarded: their usage throughout this volume is hypothetical, modeling that of auletes c. 510–400 BCE. The meaning of these technical terms mutated many times, the same words being reused in new musical contexts.

Diagram 1 presents the hypothesis visually. It is a network of tetrachords arranged on a grid that divides the octave into 21 *dieses* – literally 'leaks', or small intervals roughly a quartertone in size. This grid facilitates modulation of all kinds. It also means that there are, conceptually, 24 notes on the type of aulos for which the archaeological record is strongest. The significance of these points will be explored below. Diagram 2 provides an overview of how musicians' usage of the ethnic terms evolved in antiquity, sorting out the misunderstandings any newcomer might have in attempting to read the most advanced work on the subject, Stefan Hagel's *Ancient Greek Music: A New Technical History* (2009). I am grateful to Hagel for providing substantial feedback on earlier drafts of this diagram and for comments that spurred on my own learning. For any misunderstandings or inaccuracies that remain, I accept full responsibility.

Both diagrams are designed to stand alone as reference sheets for practitioners, or as student handouts; they make specialist knowledge that is scattered piecemeal across thousands of pages more accessible to anyone wanting to understand Classical auloi. I would commend Diagram 2 to anyone who finds Hagel's seminal book difficult, but warn them that Diagram 1 pushes further back in time than Hagel goes. It advances a model that is fundamentally incompatible with the ideas he inherited, not just from immediate predecessors, notably Andrew Barker and Martin West, but from antiquity. Most of our ancient authorities wrote on music of the fifth century BCE without ever having heard it. Conducting experimental trials on instruments of the period promises to completely change what we believe.

### ***Classical-era finger-hole boring***

In 2016, thanks to the support of the Actors Touring Company and the European Music Archaeology Project, I commissioned critical reproductions of two auloi buried at either end of the fifth century: one in southern Italy in the Greek colony of Poseidonia (later called Paestum), the other in northern Greece in the Macedonian port of Pydna. Their scales agree with reassuring exactitude but not with modern or indeed scholarly expectations. At first, it appeared impossible to reconcile their finger-hole boring with any of the interval structures described in detail by the late fourth-century musicologist, Aristoxenus. To make sense of the hole boring, we must discard conceptions that have shaped Western music for over two millennia.

Aristoxenus and the school of harmonic theory that he followed divided the octave into twelve equidistant steps. This is the octave division that enjoys global dominance today: every scale is fitted to a 12-tone grid. The fit of some scales can be quite loose, acoustically, but the grid works in practice because the fit is conceptual, not physical. The human brain is adept at fitting stimuli to the closest familiar pattern and tolerating considerable discrepancies. The 12-tone grid was developed by Aristoxenus' predecessors – fourth-century *harmonikoi*. Hagel calls it the 'old commensurable' system (2009, p. 390). What is puzzling is that this system is incompatible with the finger-hole boring of auloi made in the Classical period. The only grid that fits their hole boring satisfactorily is represented in Diagram 1. This divides the octave into seven equidistant steps and it emerged as a better option through practical experiment: a slow process of trial and error composing music on reproductions of the Pydna and Poseidonia auloi.

Kathleen Schlesinger devoted a massive book to equidistant hole boring in 1939. The archaeological evidence available to her then and her handling of ethnographic and literary evidence did not yield compelling results. The case presented here is built on finds from 1969 (Poseidonia) and 1996

(Pydna). Regarding equidistant spacing, Martin West makes an important point:

*Ethnomusicologists have found that in most pipes in most countries the spacing of finger-holes is not calculated so as to produce a rational series of intervals but is governed by the principle of equidistance. ... Some correction of notes may be made by adjusting the sizes or contours of holes, but for the rest it is taken for granted that the player will make the necessary corrections by such techniques as have been mentioned above. (1992, p. 96)*

These techniques are the ones described by Aristoxenus:

*It is not because the aulos has bore-holes and cavities and so forth that it plays fourths or fifths or octaves in true accord or gives each of the other intervals its due size, but because of skilful operation, partly by the hands, partly by the other parts with which the player has the power to raise or lower pitch. For although all the holes etc. are provided, none the less auletes mostly miss the proper intonation, for all their taking the pipes away (from each other?) and setting them parallel, blowing harder or less hard, and modifying other factors. ... Just as there is no attunement in strings unless one applies skill and tunes them, so there is none in bore-holes unless skilful operation brings them into tune.*

*El. Harm.* 2.42; West 1992, p. 96

In other words, the 'true accord' of fourths, fifths and octaves depends on the player's skill more than the instrument's hole boring.

Be that as it may, the hole boring of finds has much to tell us. It provides a scaffolding that supports and constrains the player's movements in the realm of pitch. Most of the numerous auletic finds dated to the Classical period are fragmentary or, in the case of the Elgin aulos, seriously distorted; reconstructing them involves high degrees of interpretation and creativity. The Poseidonia and Pydna auloi are in exceptionally good condition – the only serious guesswork concerns the reeds. To evaluate the way in which their hole boring supports and constrains the player, I followed Hagel's advice:

*A replica, as I have argued previously (and others have before me), is, however, not the best way to determine the intended pitches of*

*an aulos. Apart from the practical inconveniences involved in experimenting with different sizes of reeds, the unconscious efforts of any player to produce a familiar scale present a real obstacle. If possible, an evaluation should therefore start by determining an 'ideal' scale by means of calculations based on the instrument's layout; as a second step, a replica is of course most welcome to confirm the conclusions.*

Hagel 2010, p. 71

My trials playing reproductions confirm that it is disconcertingly easy to lip pitches to a scale that accords with the cultural conditioning of the player, particularly on Classical-era auloi. Even with 'stiff' reeds, the pitch-platforms provided by these instruments are unsteady. They have an alarming wobble, confirming Aristoxenus' statement that good intonation depends on the player's skill. I am therefore grateful to Hagel for sharing his predictions, generated using his dedicated aulos software, which is a tool of the utmost brilliance. Adjusting virtual reed sizes to obtain a maximum number of fourths and fifths (to within 20 cents of pure), the predicted intonation for the Pydna and Poseidonia auloi is remarkably close. Ignoring an overall difference of a semitone, seven of the eight low-register pitches coincide with a standard deviation of 2–7 cents.

Trials playing reproductions by Robin Howell (Pydna), Marco Sciascia (Poseidonia) and Chrestos Terzēs (Pydna and Poseidonia), all based on measurements by Stelios Psaroudakēs (2008, 2014), confirm Hagel's predictions. What playing reproductions reveals is that Classical aulos pitches should be understood as broad ranges, not as narrow points. Values to the nearest cent are misleading: the broad coloured bands in Diagram 2 are a better representation of pitches that are notoriously bendy. I therefore treat Hagel's optimal estimates as midpoints. They are shown at each end of the horizontal bands in coloured diamonds.

The best way to test predictions of the midpoints, I suggest, is to memorise a composition that transposes polyphonic cells (both pipes sounding together) to different scale degrees; then to run a

sequence of experiments altering one parameter at a time: the find, the reproduction of the find, the reeds and the player. *Descending Equi-heptatonic Circuits* allows such an experiment to begin. It contains cells in each of the three genera of ancient Greek music – enharmonic, diatonic and chromatic – and transposes these cells to three descending scale degrees. I have no doubt that much will be learned by changing the most complex parameter of all: the player. Auletes who have developed some competence producing pure intervals between the pipes will notice the slightest deviation from equi-heptatonic tuning. Starting the same polyphonic cell on another finger-hole feels slightly different: if the octave divisions are not exactly equidistant, the pattern of embouchure adjustments required to achieve pure intonation differs. In the cases of the Pydna, Poseidonia and Elgin auloi (with hole 6 open on both pipes), we are close enough to equidistant tuning for cyclic modulation to be entirely practical. If hole 6 is closed, this introduces a gap of a third and the polyphonic cells can no longer be so freely transposed.

Between the Pydna and Poseidonia, musical repertoire and reeds are almost completely transferable. There are only three significant acoustic differences: the Poseidonia sounds a semitone higher; the Pydna is a little louder and more pitch-flexible (because it has a wider bore); and the notes labeled G in Diagram 2 are about 27 cents flatter on the Pydna. As can be seen from the coloured horizontal bands in Diagram 2, these instruments are not tuned to have tones and semitones; the intervals between finger-holes are all much the same size, particularly on the far left of the diagram, which corresponds to the Poseidonia low pipe.

This equidistant spacing does not match the *tonoi* system developed 'with an eye to the boring of the finger-holes of auloi' reported by Aristoxenus (translated on page 26 below). The scholarly consensus interpreting this system is as follows:

*Although some of the scales stand in harmonic relations of fifths and fourths as*

*required for modulation, such a pattern is not implemented throughout. Consequently, modulation for instance between Phrygian and Lydian, or between Dorian and [old] Hypodorian, is impossible.*

Hagel 2009, p. 382

The instrument-led process of composing *Descending Equi-heptatonic Circuits* suggests otherwise. It was developed on the Pydna and Poseidonia auloi, committing to paper only a small proportion of what was tried and tested. Playing reproductions establishes that bending pitches a quartertone in either direction is easy. What has not been appreciated by writers since Aristoxenus is that this inherent instability, or available breadth in a note, makes cyclic modulation perfectly possible. Hagel's statement above is true for lyres and harps throughout history and for the mechanised auloi of the Roman Imperial period, but not for the aulos tradition that the archaeological record suggests was prominent and panhellenic in the Classical period.

### ***Equi-heptatonic systems***

For assistance interpreting the hole boring of these two finds, let us fast forward 2500 years to living musical traditions. The global success of the 12-tone grid has pushed the equidistant 7-tone scale to the margins of musical awareness. It is so undervalued today that to suggest it prevailed in the leading forms of Classical Greek music – the dithyramb and tragedy – seems ludicrous. The xylophones and gong circles of West Africa and Southeast Asia, like Classical auloi, traditionally divide the octave into seven roughly-equal steps. Describing the West African *balo*, Roderic Knight notes that ‘a builder tunes the keys with the intention of making each ascending step the same size. For a player, this translates into the ability to start a tune on any note and it will sound the same’ (Church 2015, p. 36). Terry Miller notes an equivalent functionality in the tuning of xylophones and gong circles in Thailand, Laos, Vietnam and Cambodia, but he adds an important detail:

*While it is true that Thai instruments of fixed pitch are tuned to be functionally equidistant, allowing compositions to be played starting on any of the seven pitches, equidistant tuning is not encountered with the voice, winds or string instruments, except when they must conform to the keyed percussion.*

Church 2015, pp. 188–90

This observation is crucial – it led me to the understanding presented here.

Bending an equi-heptatonic scale to produce pure intonation between the two pipes of the aulos involves making adjustments of around 16 cents – no larger than the adjustments woodwind players make in a Mozart symphony, or viol players in a Byrd fantasia. In the paneuropean musical tradition that is now global, singers, winds and string instruments do not aim to produce equidistant 12-tone tuning except, as in Thailand, when playing with keyboards and other fixed-pitch instruments. In smaller ensembles (anything one-to-a-part), skilled performers will lower major thirds by about 14 cents, so that sustained chords sound more in tune and harmonic resolutions are sweeter. Plato's friend Archytas gives us good evidence that ancient Greek musicians did likewise, aiming for pure fifths, fourths and major thirds, at least in the Dorian *harmonia* (*GMW ii*, p. 50). On a roughly equi-heptatonic aulos, producing pure intervals means widening the fifths (narrowing the fourths) by about 16 cents, and widening the major thirds (narrowing the minor sixths) by about 14 cents. Even with inflexible reeds, this is easily done, as I demonstrate in this video: <https://youtu.be/PtqUvZsW0XY?t=13m31s>.

The testimony of Classical-era writers confirms that flexibility of intonation was a defining characteristic of the aulos. Discussing attunement, Aristoxenus notes that auloi ‘are especially susceptible to variation, introduced through the craft of aulos-making, through manual techniques, and through their own peculiar nature’ (*El. Harm.* 2.43; *GMW ii*, p. 158). The allusions to it being ‘many-noted’ in earlier literature are numerous (*GMW i*, p. 57, n. 10). My own experience playing reproductions leads

me to suggest that the fundamental link in the Classical imagination between the aulos and a multiplicity of notes would have arisen from composers' exploitation of its proclivity for pitch-bending. The chromatic and mimetic opportunities are rich because, as Aristoxenus says, the instrument was made that way.

When modulating by fifths and fourths on these auloi, the average discrepancy of 16 cents per step is not the impediment to modulation that I expected it to be. This was a real surprise. Music directors who try to prevent choirs from drifting sharp or flat view any gradual tightening or slackening of pitch negatively for cultural reasons. In Classical Greece, however, choirs were accompanied by auloi, not by organs or lyres. An abhorrence of pitch drift may be one of the reasons that modulation was taboo, shamelessly and famously broken by the fifth century's avant-garde composers. But if one employs the characteristic techniques of Eastern double-reed traditions – such as portamento, timbral contrasts (fingering the same pitch two different ways) and vibrato (using a hand movement rather than the diaphragm, which means each pipe can be assigned vibrato independently) – the 16-cent discrepancies are really not so disturbing. Although they are easily veiled by larger manipulations of pitch, I suspect the cumulative rise or fall in pitch was exploited, not masked, by composers pursuing the expressive realism that came into vogue in the late sixth century. This is when the Poseidonia aulos was made, not in a cultural backwater but in one of the most prosperous colonies of Magna Graecia.

### *Unequal temperaments*

Equidistant tuning does not entirely explain the hole boring of finds. In Diagram 2, horizontal coloured bands of identical width approximate the pitch range available on each fingering – without leaking air from the finger-hole below, purely through embouchure adjustment. Using 'stiff' reeds, the range is about a tone; with 'flexible' reeds that require less pressure but more skill, the range is easily a minor third. If the

makers of the Poseidonia and Pydna auloi had been aiming for equidistant tuning, then all the coloured bands would overlap equally. They do not. To understand why not, and to explain the extraordinarily close match in tuning between two instruments separated chronologically by about a century and [in ancient journey time by at least a fortnight](#), it may help us to consider unequal temperaments in the less remote 12-tone tradition.

When keyboards are tuned to European Renaissance or Baroque temperaments, the twelve semitones are *functionally* equal but may be *audibly* unequal. When some keys are used more frequently than others, unequal steps may be desirable. For example, in the Renaissance temperament '1/4-comma Meantone,' F major is gorgeously in tune at the expense of F sharp major, which sounds hideous and was never used by Renaissance composers. The Baroque temperament 'Werkmeister III' distributes acceptable intonation more evenly, permitting the use of all twelve keys, each in two modes (major and minor); however, it still favours the most popular keys of C, G and D major. What draws aficionados to unequal temperaments is that they give each key a different colour or *ethos* ('character').

We know that dramatic realism was pursued by Classical Greek composers in ways that gave modulation a notorious prominence, like any new fashion attracting ridicule and contempt, adulation and commercial success (*GMW i*, pp. 93–8; Kowalzig & Wilson 2013, part III). I propose that 7-tone unequal temperaments flourished in the fifth century BCE for precisely the same reasons that 12-tone unequal temperaments flourished in the eighteenth century CE. They enable extensive modulation, favour the most popular keys, and contribute to the formation of a distinctive *ethos* for each key without the player needing to change instrument or retune. A 12-tone grid is excluded by the archaeological finds because, as a revival player trained in a 12-tone world, you find yourself wishing the holes were bored in different places. The problem disappears when you switch to a 7-

tone grid. Its platforms are *conceptual*, rising and falling in pitch with an elasticity for which the aulos was designed, enabling it to lead musical fashion in the direction of a more colourful dramatic expressiveness, indulging in all kinds of modulation. The reason the kithara was initially excluded from this crowd-pleasing style, I suggest, is because its pitches are inelastic. To compete, it had to add more strings. The date when strings were added is significant: the number increased from seven to eleven between the late-sixth and mid-fifth centuries (West 1992, p. 62).

### ***An inconvenient outcome***

An octave has 1200 cents. In a 7-tone system, the keys are roughly 171 cents apart ( $1200 \div 7$ ). On a piano, they are multiples of 100 cents apart. This is a problem for aulos learners and composers today: equidistant 7-tone tuning is fundamentally incompatible with all mainstream instruments except the voice and unpitched percussion. Adding it to the options in digital tuning apps would make life slightly easier. In order to give 7-tone music a chance of being understood and appreciated in a musical culture ruled by keyboards and staff notation, this score gives pitch offsets as they would appear on digital meters: multiples of 14.3 cents rounded to the nearest whole number (14, 29 or 43). 14.3 cents is the pitch creep that must be made at every step moving round the circle of fifths in order to end back at the same pitch you started at. These pitch offsets should be disregarded by players – they require no action, they are simply a reminder that this is not 12-tone music. They estimate of what the aulos will do naturally of its own accord.

For players of *Descending Equi-heptatonic Circuits*, there are two things that I consider are of prime importance. Firstly, pure intonation between the pipes. When the harmonics lock, the aulos casts a magical spell that is intoxicating; in combination with circular breathing, the effect is consistent with the role that the aulos played in ancient rituals, ecstatic and demure. Secondly, playing near the tips of the reeds is where intonation adjustments

are minimal and powers of timbral and dynamic expression are optimal. I am grateful to Robin Howell for this sage advice. To counteract the tendency of beginners to play too near the ‘onion’ of the reed, I advise relaxing the embouchure and pulling out the reed that needs to be flattened, rather than tightening and pushing in the reed that needs to be sharpened, as far as possible, in the pursuit of pure intonation.

When I started learning to play Classical-era auloi in August 2016, I struggled to make sense of them because I was trained in an equidistant 12-tone system. For over a year, I was bewildered and confused. All results were unsatisfactory. Only when I started exploring the 7-tone system did the instruments make sense. This result was neither expected nor desirable. I had commissioned the reproductions imagining that Callum Armstrong and I would be able to use them in a new production of *The Suppliant Women* by Aeschylus. The Actors Touring Company kindly gave us financial support to expand our instrumentarium and our Pydna auloi arrived six weeks before opening night at the Edinburgh Royal Lyceum Theatre. It was acutely embarrassing that we could not make sense of the instrument in time to use it in the production. We had to abandon the idea of playing fifth-century instruments in a fifth-century play, and instead use a much later instrument, the Louvre aulos. The Louvre is perfect for accompanying solo singers but really too quiet for theatre work.

With hindsight, there were two problems that prevented us from using Classical auloi in *The Suppliant Women*. First, we were playing in ensemble with pitched percussion instruments tuned to 12-tone Equal Temperament, accompanying singers who rehearsed with keyboards. Secondly, as Highland pipers, our brains were conditioned to the idea that pipes are tuned to a *musical* scale, rather than to an elastic grid that must be moulded by the player to conform to any culturally-approved scale. The need to impose a musical scale on the instrument by making embouchure adjustments every fraction of a second was

terrifying. Like learning the violin, this takes six years to master, not six weeks.

### ***Three types of modulation***

It is helpful to clarify what modulation may have encompassed in Classical Greek music. The sources indicate the co-existence of three types. Modulation by *genus* involves changing the interval structure of the basic building block, the tetrachord. Modulation by *tonos* involves transposing any interval structure to a new pitch. Modulation by *harmonia* involves switching between the six modes that we understand poorly from the Aristides scales (see Volume 3 in this series, *Vocables for Learning the Aristides Scales*). These three types of modulation would originally have been stratified – chronologically, regionally, or socially – but they evidently commingled in the course of the sixth and fifth centuries with results that progressed from being innovative to fashionable to cosmopolitan. *Descending Equi-heptatonic Circuits* explores the first two types of modulation only; the third type is explored in Volume 3. Several witnesses indicate that modulation by *genus* and *harmonia* was originally between pieces, not within them. In the fifth century BCE, chromaticism and modulation mid-strophe became a defining trait of the self-styled ‘New Music’ that emerged in Athens. This attracted fierce criticism as it rejected the ‘noble style’ established by competitive events at the Olympic and Pythian Games. There are, however, reasons to suspect that it was not as new as its protagonists boasted. A gradual evolution, building on an equally-innovative sixth century, may be nearer the truth.

The first type of modulation, by *genus*, is introduced by Aristoxenus as follows:

*Any given melody which is attuned on a single basis is either diatonic or chromatic or enharmonic. Of these the diatonic, since human nature comes upon it first, must be reckoned the first and oldest, the chromatic second, and the enharmonic third and most sophisticated, since perception becomes accustomed to it at last, with difficulty, and through much hard work.*

*El. Harm.* 19.20–29; *GMW i*, p. 139

Each tuning basis is defined by the interval structure of the tetrachord (literally ‘four strings’) – specifically, by the tuning of the two internal notes. The outer notes of the tetrachord are fixed, tuned to a pure fourth. In *Descending Equi-heptatonic Circuits*, section B is enharmonic, section C is diatonic, and section D is chromatic. This kind of modulation is like switching from major to minor in the now-global tradition, except that the chromatic *genus* before Aristoxenus was probably more a style than a particular interval structure – one that relished the inflection of pitches away from their expected position (*GMW i*, p. 225, n. 132). The earliest evidence of this threefold classification of melody is an anonymous papyrus, written at around the same time as Plato’s *Republic* (c. 380 BCE):

*They say that some melodies make people self-controlled, some prudent, some just, some brave and some cowardly, failing to understand that the chromatic (chrōma) cannot make cowards of those who employ it, and the enharmonic (harmonia) cannot make them brave. For who does not know that the Aetolians and the Dolopes and all the [. . .], who use diatonic music (diatonos mousikē), are much braver than tragedy-singers, who always follow the practice of singing in the enharmonic? Hence it is obvious that the chromatic does not make people cowardly, and neither does the enharmonic make them brave.*

*P. Hib.* i.13–22; Barker 2007, pp. 69–70

Like tragedy singers, harmonic theorists before Aristoxenus devoted themselves entirely to the enharmonic *genus*, which was regarded by cognoscenti as ‘the noble style of music that is specifically Greek’ (*ps-Plut.* 1135b; *GMW i*, p. 218). All six of the Aristides scales are enharmonic because they contain clusters of quartertones. This style was cultivated between the seventh and fifth centuries, but by the mid-fourth century had gone out of fashion. According to Aristoxenus, it was displaced by the chromatic *genus* on account of composers’ ‘endless pursuit of sweetness’ (*GMW ii*, p. 141).

The first two sections of *Descending Equi-heptatonic Circuits* use the *spondeion* (‘libation’) scale. This is similar to the

enharmonic genus but omits the quartertones. In modern terms, it is pentatonic (using five notes per octave), but in ancient Greek thinking it is trichordal, using three notes per tetrachord. It was associated with an orderly and dignified ‘few-note’ style that was upheld in opposition to the crowd-pleasing theatrical ‘many-note’ style (*GMW i*, pp. 218–9, n. 96, and p. 223). Using modern note names to indicate its interval structure, the *spondeion* scale is:

E F A B C E

This has two semitones, E-F and B-C. According to some musical experts who informed Aristoxenus, the Phrygian ‘father’ of the Greek aulos tradition, Olympus, invented the enharmonic style by splitting one of these semitones in two (*GMW i*, pp. 92, 212, 215–7). Taking the Aristides scales into account, evidence weighs in favour of it being the lower semitone, E-F, that he split, sometime in the seventh century. This is the semitone split more frequently in the melodies attributed to Olympus three centuries later (*GMW i*, pp. 223–4).

The *spondeion* scale continued to be used well into the Roman era for libations and paeans to the gods. It corresponds to scale structures still used today in China and Japan. The only ancient Greek scale structure to have enjoyed continuous transmission in the West is the diatonic genus. In the following passage, thought to have been written in the third century CE, Aristides sums up views that almost certainly derive from Aristoxenus:

*There are three genera of melody, the enharmonic, the chromatic and the diatonic, which acquire their distinctions from the narrowness or largeness of their intervals... Of these the diatonic is more natural, since it can be performed by everyone, even the wholly untutored: the chromatic is more technically sophisticated, being performed only by those who have been trained: and the enharmonic demands stricter precision, being accepted only by the most outstanding musicians, while for most people it is impossible.*

If we interpret ‘difficulty’ here as the accurate control of pitch on a Classical

aulos, this makes perfect sense. The enharmonic genus requires the greatest precision, the diatonic the least. Aristides continues, shedding light on the second type of modulation (by *tonos*):

*one kind of melody is called ‘direct’, one ‘returning’ and one ‘circular’. The direct moves from low to high, and the returning in the opposite direction; while the circular is that which modulates, as for example when one moves up a tetrachord in conjunction and then descends it in disjunction.*

Arist. Quint. I.9; *GMW ii*, p. 418

This description of a ‘circular’ melody is respected in each section of *Descending Equi-heptatonic Circuits*. The modulations are descending because a rise of a fourth followed by a fall of a fifth results in a fall of a tone. This modulation route is represented visually in Diagram 1, reading from left to right: the tetrachords rise in conjunction and descend in disjunction. The compass restriction of Classical auloi, however, means it is impossible to transpose a melody up or down a fourth without clipping. Melodic units can only rise or fall by tones and, even then, their compass is limited to a fifth (permitting three keys) or a sixth (permitting two). The ancient conception of a *systema amatebolon* (‘Unmodulating System’) reflects this limitation: a piece has not fully modulated until it has travelled *two* tetrachords in either direction, shifting *hypatē* (literally the ‘head’ or ‘principal’ note of the key) up or down one finger-hole. This kind of modulation is limited to the low register because overblowing produces the interval of a twelfth, not an octave, leaving a gap in the scale. This gap was bridged in later types of aulos, such as the Berlin and Louvre, presumably because composers wanted to transpose melodic cells of greater compass.

As the direction of modulation that Aristides describes in the passage above is ubiquitous in European Baroque music, musicians reared in the Western tradition should note that the conventional route in the sixth century BCE was in the opposite direction. A tradition related by Plato’s elder brother, Glaucon, concerning the

invention of the *nomos trimelēs* suggests that the orthodox progression was Dorian–Phrygian–Lydian, with the keynote *hypatē* climbing finger-hole by finger-hole. This route – up by a fifth, down by fourth – is mentioned by Aristides when he returns to modulation three chapters later:

*the production of a melody in a particular way ... has three forms of agōgē* [‘rearing,’ a disciplined and prestigious training], direct, returning and circular. Direct agōgē is that which makes an ascent through successive notes, returning agōgē is that which brings about depth of pitch through notes that follow each other, while circular agōgē is that which proceeds upwards in conjunction and downwards in disjunction, or conversely, and is also treated as a type of modulation.

Arist. Quint. I.12; *GMW ii*, p. 431

The converse direction is represented in Diagram 1 by reading from right to left. The practice of ascending by adjacent finger holes, incrementally raising the intensity over several minutes, is highly esteemed in the pibroch and launeddas traditions. The most impressive example I have heard, however, was a *neyjofti* solo performed by the Iranian piper, Saeid Shanbehzadeh, at the William Kennedy Piping Festival in 2005. Due to the restricted compass of the *neyjofti*, the number of notes available gradually reduced from six to five to four as the focal tone rose. The result was thrilling. Shuttling back and forth between two focal tones is the more conventional harmonic behaviour, pervasive in most musical traditions; rising twice in a row provokes an exhilarating emotion because it is unusual. If I were designing an experiment reconstructing the *nomos trimelēs*, I would complement Shanbehzadeh’s single-reed tradition from the Persian Gulf with double-reed traditions from elsewhere in Asia to avoid the very real problem of cultural bias. It is no good replacing one limited perspective with another: in the discipline of Very Early music, intercultural collaboration is as important as interdisciplinary teamwork for the credibility of results. To what extent does *Descending Equi-heptatonic Circuits* reflect my musical formation, much of which was

spent playing Baroque music? Had I been a Turkish or Iranian piper, I suspect I would have composed ‘Ascending’ circuits. A descending direction may, of course, have been orthodox in another genre of aulos-based music, in which case the lament would be a strong candidate.

### **Five types of aulos**

One of the insights gleaned from playing several types of aulos in the same concert, each with different finger-hole spacing, is that the hours of training and reed maintenance required rise in direct proportion to the number of instruments being played. A single aulos seems more plausible for amateur and educational contexts, even for the average professional, multiple instruments being realistic only for the most dedicated individual who trains several hours a day. Without this level of ongoing training, the fingers will revert under stress to whichever hole spacing is most deeply embedded: the autopilot of a woodwind player’s neuromuscular conditioning. Moving a finger hole by so much as 1mm can be catastrophic, such is the precision gained – and neuroplasticity lost – through years of practising. It is much easier to switch to an instrument that produces a higher or lower pitch than to one that produces a different scale.

This perspective alters how we interpret the vital scraps of literary evidence concerning aulos classification. There are basically five sources giving substantial details, two from the fourth century BCE and three from around five hundred years later. The first is by Aristotle, who informs us that ‘girl’ auloi were higher-pitched than ‘boy’ auloi (*GMW i*, p. 267, n. 30). The second is a lost work by Aristoxenus, *On the hole boring of auloi*, which Athenaeus quotes as follows:

*there are five sorts of aulos: girl* [parthenios], *boy* [paidikos], *kitharist* [kitharistērios], *grown-up* [teleios], *hyper-grown-up* [hyperteleios].

Ath. 634e; Hagel 2010, p. 74, n. 22

This quotation survives in a colossal compendium of ‘table-talk’ compiled in

Egypt, probably in the early third century CE. The same list appears hundreds of pages earlier, probably derived from the same source:

*[The Alexandrians] are highly musical in respect of auloi too, not only those called ‘maiden-pipes’ and ‘child-pipes’, but also the man-pipes, which are called ‘complete’ and ‘extra-complete’, as well as the kitharistērioi and the dactylic.*

Ath. 176f; *GMW i*, p. 266–7

The addition of dactylic is puzzling – it is unclear how a ‘finger’ aulos would differ from the other types listed. Perhaps it does not belong in this classification system. Comparing Hagel’s and Barker’s translations is instructive. Both could be misleading, however, were it not for our third source, written in the second century CE by Julius Pollux. His ten-book *Onomasticon* quotes numerous lost works concerning Classical Attic culture. Barker summarises the relevant information as follows:

*Pollux (IV.81) tells us that [kitharistērioi auloi] were called by this name because they accompanied the kithara; and he adds (IV.83) that there were nomoi kitharistērioi, pieces for kithara without the voice, called iamboi and pariambides, which were accompanied by auloi. ... Pollux also says (IV.81) that parthenioi auloi accompanied the choral songs of maidens, paidikoi those of boys, hyperteleioi those of men, while teleioi, also called Pythikoi, were used for the ‘chorusless’ pythikon aulēma, i.e. the auletic solos typified by the Pythikos nomos, and also to accompany paeans.*

*GMW i*, p. 267, n. 30

This may be our most valuable source as it clarifies the earlier two. The fourth source, written at about the same time, introduces confusion by classifying auloi in what appears to be a radically different way. Aristotle, Aristoxenus and Pollux agree in classifying them by performing context: the genres prescribed for competitive or religious occasions. Pausanias classifies them using the ethnic terms that distinguish either interval structures (*harmoniai*) or keys (*tonoi*). In a ten-book description of Greece, essentially a travel guide, he writes:

*There is a statue of Pronomus, a very great favourite with the people for his playing on the aulos. For a time auletes had three forms of the aulos. On one they played Dorian music; for Phrygian melodies auloi of a different pattern were made; what is called the Lydian mode was played on auloi of a third kind. It was Pronomus who first devised an aulos equally suited for every kind of melody, and was the first to play on the same instrument music so vastly different in form.*

Paus. IX.12.5; W.H.S. Jones (1918)

The ethnic terms are clearly being used for musical styles here – modes not keys – rather than the Aristoxenian usage, which is for transpositions of the Dorian interval structure. The same modal classification is found in our fifth and final source, which like the first survives in Athenaeus’ compendium. This time, the author is unidentified:

*In the old days, a noble beauty was carefully preserved in music, and every aspect kept to the orderliness proper to it, in conformity with the principles of the art. That is why there were special auloi, one for each harmonia, and in the competitions each aulete had auloi to suit each of the harmoniai. It was Pronomos of Thebes who first played all the harmoniai on the same auloi.*

Ath. 631e; *GMW i*, p. 291

There must be some kernel of truth in this, but I am more inclined to take the earlier sources at face value. The only fourth-century evidence that has come to my attention for classifying auloi by mode, rather than by performing context, is a passage by Aristoxenus that mentions the ‘Hypophrygian aulos’ (quoted on page 26 below). The context in which this occurs implies that each of the six *harmoniai* had its own special aulos. There was a Phrygian aulos, without doubt, visually identifiable by the curved horn attached to its lower pipe. Was a Hypophrygian aulos effectively a bass version, adding lower notes out of reach of the fingers? The evidence surveyed by Martin West for what was almost universally regarded as the ancestor of all Greek auloi includes an eighth-century bronze figurine and this letter:

*In about 245 BC a Greek official in an Egyptian town was making arrangements for a party, and wrote to a colleague, 'Make every effort to send me the aulete Petous with both his Phrygian and his other pipes.'*

West 1992, p. 91

The question is, which of all these types are our finds from Poseidonia and Pydna? Regional types and musical dialects would have persisted long after the development of a panhellenic aulos. The idea prompted by my practical experiments of a compositional nature is that what defined the cosmopolitan instrument was a hole-boring that abandoned ethnic identity in favour of modulating capacity. The introduction of solo aulos contests at the Pythian games in 586 BCE potentially marks the emergence of a panhellenic style, or at least the beginning of this process. The date proposed in previous studies for the assimilation of ethnic scale structures is the late fifth century. Pronomus and Eratocles are given credit for different stages in a process of systematisation and the conjecture that a relatively disorganised set of modes were tidied up to fit on a 12-tone grid in a cyclic fashion is widely accepted as fact. An assumption related to this is that composers who boasted about their 'New Music' were the first to modulate extensively. What troubles me about these two assumptions is that auloi appear to have been intentionally designed to have a note-breadth of around 200 cents since the late sixth century. With training, this makes any scale possible. All the notes overlap. Diagram 2 suggests where the precise interval structures of the Aristides scales could be played, but in practice they easily slip a little higher or lower in pitch, which means that a player may hop from any scale to any other and back again with complete freedom. This requires training but gives auletes rich opportunities for chromaticism and modulation. In fact, the pitches are so wobbly that modulation happens unintentionally when you are learning. I spent eighteen months not knowing what mode the instrument was in. Skill is required to prevent modulation and control

it; to be in charge of the instrument rather than it imposing its wild ways on you.

When we take into consideration the fact that the colourful, dramatic style associated with the aulos became fashionable in the late sixth century, this dual assumption concerning the history of modulation collapses. This composition supports the hypothesis that theatrical harmonic twists flourished in the dithyrambs and tragedies of Attic *Dionysia*. Lyre players, however, would be excluded from the colourful tonal world of aulos-based music because they cannot bend pitches. The immense popularity of the emerging dramatic style triggered an 'aulisation' of the kithara in the late sixth century. This involved increasing the number of strings from seven to around eleven (Kowalczic & Wilson 2013, p. 243). I suggest that what Timotheus succeeded in doing in his 'New Music' was not *inventing* extensive modulation, but imitating what the aulos had already been doing for a couple of generations, applying new harmonic excitement to tired, ancient kitharodic genres that were losing audience. If this interpretation is correct, then the Poseidonia and Pydna auloi would be examples of the *teleios* or *Pythikos* aulos used for solo pieces, for accompanying paean, for men's dithyrambic contests and for tragedy before Pronomos.

What, then, is the instrument developed by Pronomos in the late fifth century? If it is one of the five types listed by Aristoxenus, it could only be the *hyperteleios* aulos and the un-extended *teleios* aulos would be its predecessor. I conjecture that what Pronomos did was to extend its low register downwards, adding keys that enabled a more expansive melody to be transposed without clipping the top or bottom notes. In this case, the aulos that accompanied choruses of men in the dithyramb and drama before Pronomos would be the same as the solo instrument: the *teleios* aulos. Although this interpretation involves considerable speculation, it has the merit of being supported both by the archaeological record and by a comprehensive assembly of literary evidence. We do not have to invent missing instruments, persuading ourselves that the auletic finds are unrepresentative;

reject some historical tales as fictional while accepting others; or confer higher levels of achievement to the later period, which is easy to do because the quality of information is more impressive. Nevertheless, just as previous scholars have been influenced by Aristoxenus and ‘old’ history skewed by his superlative writings, so this ‘new’ history may be skewed by my attraction to the Pydna and Poseidonia auloi.

To explain the modal classification of our fourth and fifth sources, we have two options. We could view Pausanias’ report as relating to a seventh-century reality, in which case the word *harmonia* in the anonymous fifth source would be a simple mistake. Replacing it with the word ‘event’ solves the problem because each of the auloi in Aristoxenus’ list was used in a different panhellenic event. Alternatively, we could posit the following hypothetical scenario for around 530 BCE, a century before Pronomus. An ambitious competitive aulete becomes frustrated with having to lip intervals into tune. To beat his competitors, he wants to play faster without compromising his intonation. He realises that the embouchure adjustments traditional on a standard aulos are a hindrance to this ambition. He therefore takes a knife to enlarge two finger-holes, sharpening the notes he has to lip up in one particular *harmonia* – or he asks his aulos maker to produce a new instrument with the holes in the optimal positions for that mode. His efforts are rewarded: he wins the panhellenic prize. Pleased with his success, he ends up with a fleet of special instruments – one for each mode – and other auletes quickly catch on because competition is intense and the stakes are high. Pindar’s ode celebrating the victor from Akragas (Agrigento, Sicily) in 490 BCE indicates the level of prestige involved – as much for the city state as the competitor, as in football or the Olympic games today (see Volume 4 in this series, *Pindar’s 12th Pythian Ode*). For a century or so, these *harmonia*-specific auloi co-exist with the older panhellenic aulos. The latter is more widespread and the only one (so far) represented in the archaeological

record. The competitive advantage of a single-mode aulos comes at a price: more instruments to purchase, maintain and practice. It would open up new musical possibilities from which a distinct style would evolve, one that was no longer encumbered by constant embouchure adjustments.

Knowing what French horn players and violinists can achieve, even by the age of 13, it would be foolish to imagine that having to make pitch adjustments on a note-by-note basis lowers the potential for artistic achievement or virtuosity; it changes what is possible *stylistically*. I suspect that the microtones of the enharmonic style were an artistic solution that made a virtue out of intonation discrepancies. On the Poseidonia, Pydna and Elgin auloi, you always get a salty dissonance if you don’t lip the intervals into tune, or lip them the wrong way. Relishing interference beats would explain why the enharmonic style was so highly revered: the peaks of sensory dissonance are higher and controlling them tastefully demands consummate skill.

### ***Pitch creep***

Diagram 1 shows how cyclic modulation by conjunction (fourths) and disjunction (fifths) is possible on a grid that divides the octave into seven functionally-equidistant steps. On any instrument that supports pitch bending, the adjustment required when modulating to the next tetrachord in either direction is trivial: on average, only 14 cents. Progressing further in either direction, this accumulates to produce a pitch creep. Handled skilfully, this creep could be imperceptible, spread out over a passage of music or masked by vibrato and portamento. Alternatively, it could be harnessed to theatrical or religious purpose, provoking emotions such as anguish or ecstasy.

I discovered that a 7-tone circle of fifths was viable by accident, first playing the aulos then by singing unaccompanied, solo and with an unsuspecting community chorus. I would never have predicted that equi-heptatonic tuning could support extensive modulation of polyphonic cells in

Just Intonation and only recommend it as a practical solution because it is easy to execute, surprisingly so for musicians reared in a 12-tone world. Although it feels like what the instrument was designed for, this is not sufficient reason to believe it. It is a guess, informed by playing these instruments. Testing by others is now required to identify weaknesses that I have not seen. This may interest researchers in other fields because every music director and vocal coach struggles to prevent singers from drifting sharp or flat. My informal experiments, leading audiences of untrained singers in the warm-up included in Volume 3, suggest that the 7-tone circle of fifths with elastic gridlines accommodates the evolutionary predispositions of singers at least as well as the 12-tone system with rigid gridlines.

The teachings of Pythagoras and calculations of Plato's friend Archytas suggest that Classical auletes and their audiences cherished pure intervals between pipes. If we accept this, then the auletic finds from their lifetimes indicate that pure intervals required embouchure adjustments *all the time*. Boring finger-holes a seventh-octave apart makes cyclic modulation easier because it keeps the size of these embouchure adjustments to a minimum. Going round the circle of fifths in 7-tone equal temperament – playing pure intervals *and* returning to the starting point – involves adjusting one pipe by 14 cents and the other by 2 cents, stretching fifths and narrowing fourths by 16 cents. This gives a pitch creep of, on average, 14 cents per step. If the temperament is unequal, then the embouchure adjustments will be larger in some places, smaller in others. The temperament reveals which keys were favoured.

Between the Pydna aulos (made in the late fifth century) and the Megara auloi (made in the late fourth century) the principle of hole-boring changed. Two interval categories begin to emerge: tones and semitones. The most compelling explanation for this change, I suggest, is that an auletic 7-tone cycle of fifths was eclipsed by a kitharodic 12-tone cycle of fifths. Equi-heptatonic hole boring supports

7-tone modulation, whereas a mixture of tones and semitones supports 12-tone modulation. What previous studies have not understood is that *both* systems support extensive modulation of all three types.

This hypothesis overturns conventional thinking, which is that auletes before Pronomus could not participate in the 'exharmonic twists' and 'perverted ant-crawlings' of the so-called New Music (*GMW i*, pp. 236–7). *Descending Equi-heptatonic Circuits* demonstrates that this is wrong. Depending on whether our witnesses resisted or welcomed change, what was 'New' here was either the corruption of kitharodic *nomoi* by the aulos, or the revitalising of an illustrious genre that had become tedious (*GMW i*, p. 96). Extensive, indeed infinite possibilities of modulation are as available on the aulos as they are on the violin. The auletic record proves that this had been the case since at least the sixth century. It is modulation on an elastic 7-tone, not a rigid 12-tone grid, and doing it proficiently takes years of training. The compass of a polyphonic cell transposable into three keys is limited to a fifth, but this limitation does not, of course, apply to singers.

### ***How big is a diesis?***

On a doublepipe with launeddas-style single reeds, pitch adjustment using the embouchure is impossible – the only way to bend a pitch is to uncover a finger-hole slightly, so that it leaks air. The word *diesis* (literally a 'leak') may have acquired its musical meaning in a single-reed environment, before double reeds became standard in the Greek aulos tradition. Pitch adjustment by embouchure becomes possible with double reeds. If the pitch platforms are unsteady, because the reeds are flexible and easier to blow, then embouchure adjustments become essential to produce pure consonances between the pipes. Double reeds offer greater ranges of pitch, dynamics, timbre and articulation; but fundamentally they give pipers greater harmonic freedom, abandoning a fixed drone. It is acoustically impossible to produce pure consonances using single

reeds unless there is a fixed drone against which all notes are tuned – a single reference point. If you change the drone, you have to retune the instrument. To execute the hundreds of intonation adjustments required in *Descending Equiheptatonic Circuits*, I find it easier to use the embouchure, but I have no doubt that partially uncovering finger-holes was an additional technique used by some if not all Classical auletes. The embouchure method, however, supports greater speed and agility because the movements are smaller and the mechanical operations of note change and note inflection are physically separated.

As Hagel notes, the diesis was established as the unit of measurement for interval structures at least a generation before Aristoxenus:

*Aristotle cites the diesis as the measure in music among measures of daily use such as the foot for distances or the mina for weights: An. post. 84b; Met. 1016b; 1053ab.*

Hagel 2009, p. 152, n. 39

When a set of disparate scale structures have been aligned to a regular grid, rationalising every interval as a multiple of one diesis, the scale structures are ‘commensurable’. This has practical as well as philosophical merits. If the triplets of the ancient instrumental notation were developed by auletes and represent pitches one diesis apart, it is reasonable to suppose that they originally divided the octave into 21 dieses ( $3 \times 7$ ), conceptually splitting equidistant scale steps in three. Aristoxenus, however, adopted the octave division of 24 dieses ( $2 \times 12$ ), splitting twelve semitones in two, which would reflect kitharodic practice. The difference in size is barely perceptible: only 7 cents. The ‘auletic’ diesis would be  $1200 \text{ cents} \div 7 \text{ equidistant steps} \div 3 \text{ dieses per step} = 57 \text{ cents}$ . The universally-recognised ‘kitharodic’ diesis is  $1200 \text{ cents} \div 12 \text{ equidistant steps} \div 2 \text{ dieses per step} = 50 \text{ cents}$ .

A passage by Aristotle supports this conjecture. Before reading it, however, we need some understanding of Pythagorean teachings. These may in any case be more relevant to the Poseidonia aulos, probably made in Pythagoras’ lifetime, than ideas

developed in the fourth century. Writing in the late second or early third century CE, Sextus Empiricus transmits the following:

*The Pythagoreans ... are in the habit of sometimes saying ‘All things resemble number’, and of sometimes swearing this most fundamental oath: ‘No, by him that gave to us the tetraktys, which contains the fount and root of ever-flowing nature.’ By ‘him that gave’ they mean Pythagoras (for they deified him); and by ‘tetraktys’ they mean a number which, being constituted out of the first four numbers, fits together the most perfect number, as for instance ten: for one plus two plus three plus four makes ten. This number is the first tetraktys, and is described as the ‘fount of ever-flowing nature’ in as much as the whole universe is organised on the basis of these numbers according to harmonia; and harmonia is a system of three concords, the fourth, the fifth and the octave; and the proportions of these three concords are found in the four numbers previously mentioned, in one, two, three and four.*

*Adv. Math. vii.94–5; GMW ii, p. 30*

On a monochord, string lengths in the ratios 4:3, 3:2 and 2:1 produce the intervals of an octave, fifth and fourth respectively. This information concerning the Pythagoreans enables us to interpret the passage by Aristotle. It concerns a traditional way of dividing up the tonal space available on the aulos:

*Some people say that there are many such [numerical correspondences]: for instance the mesai are respectively 9 and 8 [i.e. monochord string lengths for the notes mesē and paramesē are in the ratio 9:8]. They point out also that the interval from alpha to omega in the alphabet is equal to that from the lowest note to the highest in auloi, whose number is equal to the whole system of the heavens.*

*Metaphysics 1093a 29-b4; GMW ii, p. 73*

In Pythagorean philosophy, the ‘whole system of the heavens’ has ten spheres: the earth, counter-earth, moon, sun, Venus, Mercury, Mars, Jupiter, Saturn and the stars. Aristotle says that they added the counter-earth in order to explain eclipses of the moon and ‘to raise the number of heavenly bodies around the central fire from

nine to ten, which the Pythagoreans regarded as the perfect number' (*Metaphysics* 986a 8–12). The basic *tetraktys* is  $1+2+3+4$ , which equals 10, but the reference here here is to its other manifestation,  $1\times 2\times 3\times 4$ , which is 24.

For the correspondence these Pythagoreans saw between the 24 letters of the alphabet and the notes of the aulos, a division of the octave into 24 dieses proves unsatisfactory for two reasons. First, the low registers of the Pydna and Poseidonia auloi would have 25 notes (a complete octave, counting extremities). Secondly, even using inflexible reeds, the low register comfortably exceeds an octave owing to the range of pitch available on each fingering. A 21-diesis division is much more satisfactory. A single octave gives us 22 notes and stretching this by a diesis at either end brings the total to 24. Diagram 1 shows precisely this number of notes, not because I had interpreted this passage by Aristotle in this way, but because when composing enharmonic music on the Pydna and Poseidonia auloi, 24 is the number of notes I found I could comfortably play.

The practice of stretching a compass by one diesis at either end finds oblique support in the first Aristides scale, which is called (Slack) Lydian. In Diagram 2, it is numbered 1 and the stretched notes, top and bottom, are coloured gold. Stronger support for this interpretation may lie in the sequence of 24 letters (alpha to omega) assigned to pitches one diesis apart in the ancient vocal notation. Did these pitches originally correspond to the low register of an aulos? If so, then the Elgin is a candidate. When the symbols are used in a fixed-pitch sense (which is not always the case), the pitch of sigma (C) is thought to lie between F and F sharp (Hagel 2009, p. 93, Diagram 22). This brings the low register of the Elgin into alignment with the sequence alpha to omega in Hagel's diagram of the fully developed notation system (2009, pp. 13 and 93).

Aristoxenus refers to a 28-diesis diagram produced by Eratoclean theorists, probably in the first half of the fourth century. Barker considers it most likely that the Aristides scales were extracted from this diagram

(2007, pp. 45–8) and Hagel offers a reconstruction (2009, p. 377). Barker's suggestion is consistent with a division of the octave into 21 dieses because the notes out of range in Diagram 2 require an extension of four dieses to fit within the system. Perhaps this captured on papyrus what Pronomus achieved in practice, adding lever-mechanisms that extended the low-register compass from 24 notes to 29. The number of notes is always one higher than the number of intervals.

### *The fourth-century reform*

Previous scholars have unanimously agreed that the fifth-century fashion for 'exharmonic twists' and 'ant-crawlings' led to a tidy-up operation by the school of Eratocles – the *harmonikoi* referred to by Aristoxenus. Organizing a disparate collection of ethnic modes into a unified, cyclic system of keys appeared to be a neat musical corollary to the Greek spelling reform (the Athenians voted to introduce a standardised alphabet in 403/2 BCE and during the fourth century this displaced local alphabets throughout the Greek-speaking world). Above, I argued that the evidence points to a considerably earlier date for the assimilation of regional interval structures (Phrygian, Lydian, etc.) into a 'commensurable' system that supported modulation. The aulos was originally a foreign instrument, played by Phrygians and Lydians, but it had taken root in Greek musical culture by the mid seventh century (*GMW i*, p. 51; West 1992, p. 82). If a grid supporting extensive modulation emerged in the sixth century, at least for auletes, then the fourth-century reform must have been of a different nature.

Mode-related and key-related notions of *tonos* are intertwined in the literary sources. Sense can be teased from the confusion if *tonos* is understood as one of a progression of concepts, evolving, accumulating and co-existing. In chronological order, these concepts would include focal tone, tetrachord, octave and the two-octave interval structure called the 'Greater Perfect System'. Barker concludes:

*what [Aristoxenus] wrote was sufficiently obscure or involved to breed nonsense in the minds of some of his later followers. Given the use of the same term, tonos, in the two different contexts [mode and key], and the use of the same names both for harmoniai and for tonoi in either of their roles, the ambiguities were always likely to create confusion.*

*GMW i*, pp. 26–7

We can bring some clarity to the picture by positing that the octave concept of *tonos* coincides with the Dorian *harmonia*, or central octave of the Greater Perfect System. Interpreted thus, we need no longer dismiss the following story as corrupt:

*Sacadas of Argos, who composed songs and elegaic poems set to music ... was also a fine aulete, and it is recorded that he won the Pythian contest three times [in 582, 578 and 574 BCE]. He is mentioned by Pindar. In the time of Polymnestus and Sacadas, there were three tonoi, Dorian, Phrygian and Lydian: and it is said that Sacadas composed a strophe in each of them, and taught the chorus to sing the first in the Dorian tonos, the second in the Phrygian, and the third in the Lydian: this nomos is said to have been called Trimelēs because of the modulation. But in the document at Sicyon concerning the poets, Clonas is recorded as being the inventor of the Trimelēs nomos.*

*Ps-Plut.* 1134a–b; *GMW i*, pp. 213–4

This was written in about the second century CE and is thought to quote or paraphrase a historical work by Plato's elder brother, Glaucon. Projecting the two-octave meaning of *tonos* from the late fourth century onto a tradition that has its origins 150 years earlier has caused both Barker and Hagel to reject this tradition as mistaken. As witnesses of musical behaviour, physical instruments are certainly more reliable than stories written generations later, but this particular tradition, unlike that for classifying auloi by mode, has no contradictory witnesses. Although we cannot be sure it is by Glaucon, this appears likely. It may be interpreted in a way that is entirely consistent with the auletic record and the dispute between Clonas and Sacadas is easily resolved. For example, Sacadas may

have composed a choral ode (an 'aulodic' *nomos*) and Clonas a solo piece (an 'auletic' *nomos*). *Nomos* (literally a 'custom' or 'law') in this context means a type of composition given canonical status by its selection for competitive or religious occasions (*GMW i*, p. 249). It appears that the issue here is not the story transmitted by pseudo-Plutarch, but the scholarly model – over two thousand years of Western musicological belief, as crystallised in the cyclic arrangements of tones and semitones known as the seven octave species (*GMW ii*, pp. 15–21). Projecting this conception onto aulos-based music is incompatible with the hole boring of Classical finds, as Schlesinger guessed in 1939 but with insufficient archaeological evidence to prove her case.

A more resilient model emerges when we first give the key-related notion of *tonos* a deeper history; and then recognise that the enharmonic octave species of Eratocles (c. 400 BCE) did not necessarily fit the same grid as the diatonic octave species of Cleonides (? first century BCE) and Ptolemy (second century CE). The notion that mode-related aspects of *harmonia* had chronological precedence to key-related aspects of *tonos* is undermined by practical experiment and all forms of evidence: literary, material and ethnographic. Transforming the melody by altering its scale structure is what happens when you set off in the wrong tuning, or a lyre string slips in mid-performance; transposing the same melody to a new pitch happens when you set off on the wrong note (on an equiheptatonic instrument), or your voice finds a lower or a higher pitch more comfortable. I suspect that musicians were exploring both possibilities (modes and keys) for thousands of years before the Classical period. What Diagram 1 offers is a practical framework that allows three things to co-exist: octave species (a cyclic reordering of intervals); transpositions of the same interval structure (*tonoi*); and different scale structures (*harmoniai*). The gridlines are more elastic than Aristoxenus could accept and, after the rejection of the aulos by Acibiades and Plato, it is no wonder that elite citizens were more receptive to lyre-based conceptions.

Adding a deprecated sixth-century auletic grid to our historical model enables us to accept the traditions that Sacadas and Clonas could modulate between three *tonoi*, without changing instrument, respectively a century and two centuries before Pronomus. It would be modulation in a 7-tone system, transposing a polyphonic cell spanning a fifth or less to consecutive finger-holes. The vocal melody would not be limited to a fifth, only the aulos accompaniment. Two centuries later, this might be perceived as having ‘a noble beauty’ because significantly fewer notes are involved than in the 12-tone ‘bending and twisting’ that earned the kithara players Timotheus and Philoxenus the contempt of conservative critics (*GMW i*, p. 237).

The historical model emerging from this compositional experiment is that the Poseidonia-type aulos evolved to suit the *nomos trimelēs* and the expressive modulations of other auletic genres, above all the *Pythikos* and *polykephalos nomoi*. It is the theatrical use of rhythm and harmony that the leading composer, Lasus of Hermione, appears to have taken from competitive auletic culture, introducing it to the dithyramb in the late sixth century:

*Lasos of Hermione, by altering the rhythms for the movement of the dithyramb, and by pursuing the example of the multiplicity of notes belonging to the aulos (and so making use of more notes, widely scattered about), transformed the music that existed before him.*

*Ps.-Plut.* 1141c; *GMW i*, p. 235

Lasus was a contemporary of the player of the Poseidonia aulos. He wrote the first ‘treatise’ (*logos*) on music, but precious little is known about its contents (*GMW ii*, pp. 31; West 1992, p. 225; Barker 2007, p. 19). What we do know is highly significant: Aristoxenus criticises him and some others for thinking that notes had breadth:

*... if [pitch] is not defined, it is not at all easy to say what a note [phthongos] is. Anyone who does not want to be forced into the position of Lasus and certain of the followers of Epigonus, who thought that a note has breadth, must say something rather more precise about it.*

*El. Harm.* 3.19–24; *GMW ii*, p. 128

This may be the strongest single piece of literary evidence supporting the hypothesis that emerges from this compositional experiment. Playing pure fourths and fifths on a 7-tone grid is only possible if the notes have breadth. The elasticity required is 16 cents on average, which is significantly greater than the 2 cents required on a 12-tone grid. Without bending any gridlines, the sizes in cents of the fourths and fifths are 514:686 on a 7-tone grid and 500:700 on a 12-tone grid; for pure intonation, they must be bent to 498:702. Pure consonances are critical on an aulos because, when the tuning is imperfect, the interference beats are more audible than between two lyre strings. Hagel sets the tolerance for pure intervals to  $\pm 20$  cents when using his dedicated software to predict optimal reed lengths. I wonder if this may be telling us something significant. It is consistent with an average note-breadth of 16 cents – a breadth that excludes lyres and harps from using the 7-tone grid because bending notes all the time is impractical. Not so on an aulos, although it demands years of training.

According to this hypothesis, what Pronomus did was to add the Dorian and Iastian *harmoniai* (as transmitted by Aristides) to an instrument that was already capable of playing in (Slack) Lydian, Tense Lydian, Phrygian and Mixolydian (see Volume 3 for details). Modulation mid-piece would have been made easier by the addition of lever mechanisms to operate three lower holes, out of reach of the fingers, as found on the Megara auloi. The names of *tonoi* may have been re-used (? by Damon or Lasus) as the names of *harmoniai* that had focal tones on corresponding scale degrees but possessed different interval structures. The notes Pronomus added, if this model is correct, are shown in Diagram 2, below the range shared by the Poseidonia and Pydna auloi. These developments would all have taken place long after the aulos tradition was cosmopolitan. The date proposed for the assimilation of ethnic scale structures, establishing an instrument of panhellenic identity, is pushed back to the early sixth century: sometime between the widespread adoption of the 7-string lyre and

the introduction of aulos competitions at the Panhellenic Games.

This historical model leads me to suggest that the paradigm shift taking place between Timotheus and Aristoxenus – at the same time as the Greek alphabet was being standardised – was not about enabling cyclic modulation, as previously thought, but about abandoning a dual-grid system and replacing it with a single grid. Barker writes: ‘Reputedly the most ancient and certainly the most respected class of *nomos* was the kitharodic (treated e.g. by Plato, *Laws* 700b, as the only class worth mentioning)’ (*GMW i*, p. 250). It is therefore natural that the kitharodic grid should oust the auletic one, particularly when auletes already had an instrument adapted to suit the kithara: the *kitharistērios* aulos. Abandoning the 7-tone grid meant that pipes and lyres could perform together more easily, there was only one tonal system to teach and learn, and notes did not require so much breadth. A 12-tone grid increases the number of keys available, changes the pitch relations between them and, most significantly for auletes, reduces the amount of lip bending required to play in tune.

### ***A coherent solution***

The ancient materials that have come down to us may be unrepresentative or unreliable for a variety of reasons (discussed by Barker: 2007, pp. 5–6). The hypothesis generated by this composition makes sense of conflicting stories, drawing out of a problematic evidence base a more compelling solution. The central issues have been addressed above. Here I raise awareness of four points that add coherence to the picture.

First, when Socrates famously rejects the aulos in Plato’s *Republic*, he does so because it is the original instrument guilty of modulating mid-piece in the pursuit of expressive realism:

*‘Then we shall not bring up craftsmen to make trigōnoi or pēktides [two forms of harp] or any of the instruments that have many strings and all harmoniai.’ ‘Apparently not.’ ‘Well, will you admit*

*makers or players of the aulos into the city? Or isn’t it the most numerous-noted of all, and aren’t the ‘panharmonic’ instruments themselves simply an imitation of the aulos?’ ‘Obviously,’ he said.*

Plato, *Rep.* 399d; *GMW i*, p. 132

Plato is not saying that harps imitate a specific type of aulos, nor is it plausible that these types of harp were developed in imitation of the new aulos that Pronomus had developed only a few decades earlier. Plato can only be referring to the standard, conventional Greek aulos that Pronomus inherited and both Socrates and Plato had probably studied as teenagers. Plato is excluding the aulos generically. The different types used to accompany girls, boys, men and kithara players are all refused entry to his ideal city-state. What this implies is that it was not a particular type of aulos that modulated between *harmoniai*, it was all of them. They were all capable of ‘exharmonic twists’ because, as Lasus and the followers of Epigonus believed, each note had a breadth of pitch.

Over a thousand years later, Proclus of Athens (412–485 CE) wrote:

*they say that each aulos-hole yields three notes at least, and more if the side-holes are opened too.*

Commentary on Plato’s *Alcibiades I*, 3.41; West 1992, p. 95

Compared to fixed-pitch instruments (harps, lyres and panpipes) the greater harmonic versatility of the aulos provides an excellent explanation for the moral judgement cast by Socrates, Alcibiades and Plato. The aulos was unsuitable for an elite citizen’s education because playing it involved bending pitches, leading to associations not with steadfastness and restraint but impulsive, uncontrolled and emotional behaviour.

The second point adding coherence is that one of Aristoxenus’ contemporaries, Heraclides of Pontus, differs from all other authorities in giving primacy to the triad Aeolian-Iastian-Dorian, rather than Dorian-Phrygian-Lydian. Athenaeus writes:

*Heraclides of Pontus, in the third book of his On Music, says that Phrygian should not*

*even be called a harmonia, and no more should Lydian. There are, he says, three harmoniai, since there are three races of Greeks: Dorians, Aeolians and Ionians.*

Ath. 624c; *GMW i*, p. 281

Heraclides may have been a nationalist, wanting to cleanse Greek music of its associations with Lydia and Phrygia (in what is now western Turkey), but this apparent disagreement may amount to nothing. Diagram 1 shows how the pairs of tetrachords labelled Aeolian-Lydian and Iastian-Phrygian each form an Unmodulating System, or one key brought to life by the tonal contrast between two tetrachords (conjunct and disjunct). The pair Dorian-Mixolydian forms a third Unmodulating System. When pairs of *tonoi* are married in this way, forming a single key defined by its tonal dynamism, then the auletic grid supports three keys a tone apart, rather than seven keys a fourth apart. This would explain the low profile of the seventh *tonos*, Locrian, in ancient literature: it does not participate in the triad of keys established in the sixth century by Sacadas and possibly in the seventh century by Clonas. In the Plutarchian treatise *De Musica*, immediately before the story about the invention of the *nomos trimelēs*, we learn a little more from Glaucón:

*Clonas, the composer of nomoi sung to the aulos, who lived a little later than Terpander, was a Tegean according to the Arcadians, a Theban according to the Boeotians.*

ps-Plut. 1133a; *GMW i*, pp. 210–11

This places Clonas in the seventh century and identifies him as a Greek of Aeolian identity, unlike the semi-mythical inventor of the enharmonic style, Olympus, who was a Phrygian.

The third point concerns a disagreement between Aristoxenus' predecessors:

*The exposition of the tonoi by the harmonicists is just like the way the days of the month are counted, where, for example, what the Corinthians call the tenth the Athenians call the fifth, and others again the eighth. In just the same way, some of the harmonicists say that the Hypodorian is the lowest of the tonoi, the Mixolydian a*

*semitone higher, the Dorian a semitone above that, the Phrygian a tone above the Dorian, and similarly the Lydian another tone above the Phrygian. Others add below the ones mentioned the Hypophrygian aulos; while others again, with an eye to the boring of the finger-holes of auloi, separate the three lowest tonoi, the Hypophrygian, the Hypodorian and the Dorian, by three dieses from one another, and the Phrygian from the Dorian by a tone, placing the Lydian at a distance of another three dieses from the Phrygian, and the Mixolydian at the same distance from the Lydian.*

*De Musica* 37.15ff; *GMW ii*, pp. 153–4

We can date these two *tonoi* systems to some time before 322 BCE. By then, Aristoxenus had achieved an eminence that fuelled his ambitions he might succeed Aristotle. Headship of the Lyceum, however, passed to Theophrastus (*GMW ii*, p. 119). Hagel suggests a date of 'not long after 400' for these *tonoi* systems (2009, p. 389). Anyone dipping into Hagel's book should note that he switches his terminology: the 'Second' system in the diagrams on pages 379–80 is renamed the 'old auletic' system from page 390 onwards. 'Old' in this instance means early fourth century. Another potential source of confusion is that Hypodorian is below Dorian by a finger-hole, not by a fourth, in both *tonoi* systems. This is why I call it 'old' Hypodorian in Diagrams 1 and 2, like Hagel using 'old' to mean before Aristoxenus, whose work obliterated what came before.

The interval of three dieses in the second system ('with an eye to the boring of the finger-holes of auloi') must involve 12-tone dieses of 50 cents, rather than 7-tone dieses of 57 cents, because of the larger interval between Phrygian and Dorian: a tone (four dieses). This system is almost equiheptatonic, except that the scale step corresponding to the tone of disjunction in the Dorian *tonos* is larger. This is highly significant: it eliminates the need for embouchure adjustment when moving between the concords *hypatē-mesē* and *hypatē-paramesē* – the fourth and fifth that define the key. I would interpret this *tonoi* system as an unequal 7-tone temperament,

favouring Dorian but still supporting excursions to other keys and twists of chromaticism. It would be an intermediate stage, halfway between the auletic 7-tone system and the kitharodic 12-tone system.

Finally, this hypothesis potentially offers a simpler explanation for the Dorian enigma. How did the scale that occupied a central place in Classical music education and theory end up in a marginalised position? Hagel's book provides a solution. He defines the problem as follows:

*in the notation, it is by no means the natural scale, as one should expect, but lies at the outskirts of the diagram, to be transcribed with five flats.*

Hagel 2009, p. 10

Exploring how the collapse of a 7-tone grid and rise of the 12-tone grid may explain the Dorian enigma more successfully is a topic for a future study. I will simply point out that in Diagrams 1 and 2, the interval structures with ethnic labels in blue, black and red are transposed three aulos scale-steps higher, to what Hagel concludes was their 'old' pitch, again meaning before Aristoxenus. This is convincing. With 'old' Dorian at the pitch of 'new' Lydian (labelled in green), the low register of the Pydna aulos can be reconciled with the musical genres for which professional auletes were most in demand. When the two holes out of reach of the fingers are open (the basic setup, which I use for *Descending Equi-heptatonic Circuits*), the instrument is optimised for the Phrygian *tonos* with focal tones a little sharper than G–C–D; when they are closed, the instrument is optimised for Dorian with focal tones somewhat flatter than F#–B–C#. Everything makes sense. The only proposed refinements to Hagel's model are the nature of the paradigm shift (deprecation of an elastic 7-tone grid) and the perspective of 'Lasus and certain of the followers of Epigonus, who thought that a note has breadth'. The lack of written evidence for a musical behaviour contemporary with Pythagoras and Socrates is unsurprising. What we have are the physical instruments and their testimony deserves greater attention.

## Conclusions

For this experimental composition, my goal was to respect everything scholars knew about Greek music in the period when the Poseidonia and Pydna auloi were being played (roughly 510–380 BCE). As a composer bringing critical reproductions of these finds to life, I wanted to constrain my creativity by taking every scrap of ancient evidence into account. I did not anticipate that the hole boring of these instruments would contradict both the thinking of ancient Greek music scholars and a fundamental tenet of Western music – the division of the octave into twelve semitones. This was naive. The musical tradition we are dealing with experienced profound changes in the two centuries before Aristoxenus.

*Descending Equi-heptatonic Circuits* submits for distributed testing and development what may prove to be better solutions to a number of puzzling questions. It gives due weight to the auletic record and looks to unfamiliar classical music cultures to help interpret two outstanding archaeological finds. Previous studies have asserted that cyclic modulation by fifths and fourths was impossible on Classical auloi before Pronomus; that before the late fifth century changing mode or key meant changing aulos. This composition demonstrates that extensive modulation may be much older and is entirely viable on instruments contemporary with Lasus of Hermione, provided the tonal gridlines are elastic and notes are understood as having breadth. It suggests that fourth-century theorists favoured the modulatory framework developed by kithara players in the first half of the fifth century. This did not require pitches to have breadth; instead, it involved increasing the number of strings from seven to eleven. According to this hypothesis, an auletic system of seven functionally-equidistant tetrachords (Diagram 1) was gradually eclipsed by a tonal grid that enabled kithara players to be as crowd-pleasing as auletes in a period when theatrical realism was leading musical fashion (*GMW i*, p. 300).

The aulos had been calling the tune for Greek musical culture as a whole since the late sixth century thanks to the popularity of the dithyramb and the rise of drama in Athens. But the balance of power and direction of influence seems to change in the second half of the fifth century. Timothy Power writes:

*By the 420s Panathenaic kitharoidoi were somehow felt to be intruding on the territory of the aulete – making themselves at home in the Dionysiac realm, posing an imitative challenge to the aulos-based music of dithyramb and drama. ... Plato disdains the way (Dionysiac, aulodic) dithyramb absorbs (Apolline, lyric) paian – but to have kitharodic music itself imitating aulodic music is too disturbing a symptom of late democratic cultural perversity.*

Kowalczic & Wilson 2013, p. 244

The terms need to be clarified: ‘aulodic’ and ‘kitharodic’ refer to music that involved the voice, whereas ‘auletic’ and ‘kitharistic’ refer to music that was purely instrumental. It was kitharodic culture that commanded the highest prestige, tied to the performance of Homeric epic. Traditionalists found its theatrical turn in the Classical period vulgar and deeply disturbing.

A scaffolding of seven wobbly platforms would be restricted to a double-reed doublepipe tradition that exploited pitch bending to produce pure concords between the pipes. It would support three *tonoi* a scale-step apart, each with a compass of a fifth (a vocal melody could be more expansive). A 12-tone grid, by contrast, is compatible with the inflexible pitches of harps and lyres. It supports twelve *tonoi* in theory (in practice, only about seven were used) and a highly chromatic harmonic language. The driving force behind this aulisation of the kithara was pleasing crowds at *Dionysia*: lyre players’ desire to be fashionable, doing what virtuoso auletes like Sacadas, Lasus and Epigonus had started doing in the sixth century. Ultimately, however, the kitharodic tonal system won: a dual-grid musical culture collapsed to a single-grid one.

Playing a composition like *Descending Equi-heptatonic Circuits* requires a level of

training beyond what anyone in the aulos revival has reached at the present time, including myself, but this level is no greater than what any professional skill demands. The primary purpose of this composition, therefore, is to raise the bar and provide a rewarding training experience for all learners, raising our competence levels and filling a void: players of Classical auloi currently have no repertoire to practise. In the absence of living masters, *Descending Equi-heptatonic Circuits* is a substitute for a strict teacher. For students of any instrument, the path to excellence involves venturing out of one’s depth, aiming at something slightly beyond one’s current capacities. *Descending Equi-heptatonic Circuits* provides a training ground for playing pure intervals between pipes. I have uploaded recordings and videos at various points in its development process (and mine playing it) and intend to continue doing so in order that others struggling can take heart in the knowledge that the impossible does become possible with practise.

Proponents of an open fingering system may or may not reach my conclusion, which is that closed fingering (generally opening one finger-hole at a time) avoids dropping the instrument and significantly reduces the tension and physical effort that leads to injury and technical awkwardness. I like to have as much surface area in contact with the pipes as possible, so that finger pressure can be reduced and the pipes are held lightly, not gripped.

*Descending Equi-heptatonic Circuits* is simultaneously a cultural product, serving aulos learners, and a research output in the discipline of Very Early music (see Volume 1, p. 6). As a cultural product, I hope it opens up new musical territory for composers and paves the way for intercultural collaborations, perhaps with musicians from West Africa, Thailand, Laos, Cambodia or Vietnam, whose instruments are also tuned to a functionally-equidistant 7-tone system. As a research output, I trust it provokes performers, Classicists and musicologists to look again at ancient Greek materials, asking new questions and reaching deeper insights. Learning to play Classical auloi sheds light

on the deep history of music: east, west, north and south.

The most serious limitation with this composition is my own cultural conditioning. I was reared in the Scottish pibroch and paneuropean orchestral and Baroque flute traditions. *Descending Equiheptatonic Circuits* reflects this heritage as powerfully as it reflects anything ancient Greek. Rather than attempting to undo my training, which I do not think is possible, I would recommend that future research and cultural projects make it a priority to recruit and cultivate brilliant players with roots elsewhere on the planet: virtuoso musicians from Mediterranean islands, the Balkans, the Near, Middle and Far East. A more fruitful journey will begin when we stop claiming that we know best or that what we are doing *is* ancient Greek music. Aulos players should keep their minds open, recognising that all authorities, ancient and modern, have cultural prejudices. There are other solutions to be found and the aulos revival will be healthier when it is being fed by a broader spectrum of piping traditions.

In order to encourage others to keep on pushing boundaries, I have shared editable file formats for this composition at the DOI

[10.6084/m9.figshare.7006208](https://doi.org/10.6084/m9.figshare.7006208). This is so that performers with different cultural training – for example, players of the Croatian *sopele*, Azerbaijani *balaban*, or Chinese *guan* – can recompose it easily. I would strongly encourage them to do so, exploring other possibilities and sharing results online. I would also encourage those designing future projects to take intercultural collaboration to a higher level. This could mean budgeting properly for: 1) learning to play, such as full-time 3-year studentships; 2) composing new music, which has to be by dedicated players through practical experiment; and 3) producing scores or videos that capture new compositions, a greater diversity of playing techniques, and explain the decision-making process in detail. This would build on the remarkable achievements of the European Music Archaeology Project, which has brought interdisciplinary collaboration in the aulos revival to new heights. Doing the same thing for intercultural collaboration would put the aulos revival on an even more powerful trajectory, generating new knowledge and enriching cultural life.

## Bibliography

- BARKER, A. (2007) *The Science of Harmonics in Classical Greece*. Cambridge: Cambridge University Press.
- CHURCH, M. (ed.) (2015), *The Other Classical Musics: Fifteen Great Traditions*. Woodbridge: The Boydell Press.
- GMW i. A. Barker (1984), *Greek Musical Writings I: The Musician and his Art*. Cambridge: Cambridge University Press.
- GMW ii. A. Barker (1989), *Greek Musical Writings II: Harmonic and Acoustic Theory*. Cambridge: Cambridge University Press.
- HAGEL, S. (2009) *Ancient Greek Music. A New Technical History*. Cambridge: Cambridge University Press.
- (2010), ‘Understanding the aulos Berlin Egyptian Museum 12461/12462’. In Ricardo Eichmann, Ellen Hickmann and Lars-Christian Koch (eds), *Studien zur Musikarchäologie* 7. *Orient-Archäologie* 25, pp. 67–87.
- KOWALZIG, B. and P. Wilson (eds) (2013), *Dithyramb in Context*. Oxford: Oxford University Press.
- PSAROUDAKĒS, S. (2008), ‘The aulos of Pydna’. In Arnd Adje Both, Ricardo Eichmann, Ellen Hickmann and Lars-Christian Koch (eds), *Studien zur Musikarchäologie* 6. *Orient-Archäologie* 22, pp. 197–216.
- (2014) ‘The aulos of Poseidōnia’. In Angela Bellia (ed.), *Musica, culti e riti nell’Occidente greco*. *Telestes. Studi e ricerche di archeologia musicale nel Mediterraneo* 1. Pisa and Rome: Istituti Editoriali e Poligrafici Internazionali, pp. 117–29.
- WEST, M. L. (1992) *Ancient Greek Music*. Oxford: Oxford University Press.