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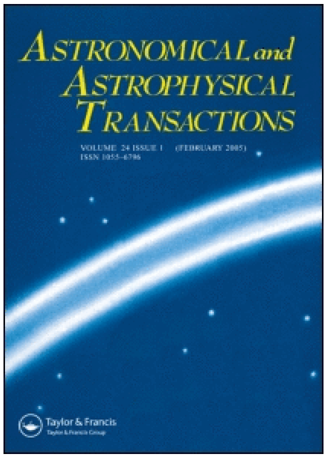

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THE DRACO CONSTELLATION: THE ANCIENT CHINESE ASTRONOMICAL PRACTICE OF OBSERVATIONS

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The Draco constellaton is one of the oldest ancient constellations. It is appatently connected with the very archaic practice of observations and with an ancient Chinese astronomical observational practice during the most ancient times.

KEY WORDS **Draco constellation, observations of the circumpolar stars**

1 A MODERN DATING OF THE CONSTELLATIONS ORIGIN

This short excursus follows a compact review from (Gurshtein, 1993):

"It was E. W. Maunder who considered that the constellation-makers had lived around 2700 BC at a latitude between 35° to 40° north. A. C. D. Crommelin arrived at a similar result. More recently Michael W. Ovenden dated the origin of the constellations as 2600+800 BC and took the geographical latitude of the constellation-makers to be 36° + 1.5° North. Archie E. Roy, continuing Ovenden's work in analysing the list of the constellations in Aratus' poem "The Phaenomena", suggested that they had come from Crete in the early Minoan period being derived from the Sumero–Akkadian astronomerpriests observations.

Most researchers believe that the Babylonian tradition of the formulation and naming of constellations was handed down from Sumer and Akkad. According to W. Hartner, it is actually more ancient and "had its origin about or even some time before 4000 BC with the prehistoric settlers of Persia, Elam, and Mesopotamia, and it was taken over by the Sumerians and Akkadians, from where it eventually passed over to the Greeks." We have to note that in some cases this point of view is categorically rejected."

Gurshtein in his hypothesis on the origin of the Zodiacal constellatons argued, that the development of the twelve houses of the Zodiac in three groups of four lasted over some six millenia.

2 WHY HAVE THE CONSTELLATIONS APPEARED?

Van der Waerden thought (van der Waerden, 1974), that major reason for this phenomenon is the appearence of a starry sky, having struck the mind's eye of men in ancient epochs. It was probably the initial point of beginning of mythology, religion, astrology and in the end after all these astronomy (including the phenomenon of the origin of constellations). At least it is absolutely true concerning ancient China. J. Needham supposed (Ronen, 1981) that "astronomy was a science of cardinal importance to the Chinese, since it arose naturally out of that "cosmic religion", that sense of the unity and even" ethical solidarity "of the universe, which led philosophers of the Sung to their great organic conceptions. Moreover, the establishment of a calendar by the imperial ruler of an agricultural people, and its acceptance by all those who paid allegiance to him, are threads which run continuously through Chinese history from the earliest times. Correspondingly, astronomy and calendarical science were always orthodox, "Confucian", sciences, unlike alchemy, for example, which was typically Taoist and "heterodox". It has been well said that while among the Greeks the astronomer was a private person, a philosopher, a lover of the truth, as often as not on uncertain terms with the priests of his city; in China, on the contrary, he was intimately connected with the sovereign pontificate of the Son of Heaven, part and parcel of an official government service, and sometimes ritually accommodated within the very walls of the imperial palace.

And the importance of the Chinese observations is not lessened one whit by the fact that the observations of earlier centuries were often due to the belief in the importance of the heavens as foretelling State affairs. After all, astrology in Europe was a long lasting and in a narrower, individual form it persisted until the time of Johannes Kepler in the seventeenth century; indeed it is still a popular superstition today."

3 WHAT ARE THE AIMS TO SINGLE OUT CONSTELLATIONS?

J. Gershel thought (A. Berry, 1904), that in many cases a selection of stars for constellations was very much at will, making for various confusions and jumble. "Numberless snakes curve in long circles, that cannot remember any memory, over all celestial spheres bears, lions and fishes, great and litlle, confuse hopelessly the recognition of constellations"

Accordingly the point of view of Flammarion (1875) was that some of the constellations were selected in a yearly sun way among stars. Many other scholars had a similar point of view.

Gurshtein had another point of view (Gurshtein, 1993):

"If the design of the constellations had been motivated by the picture principle, that is by the combining of noteworthy starry groups, they should consist of bright stars with the easily remembered configurations first of all. Certainly there are constellations that are distinguished in accordance with the peculiarity of their

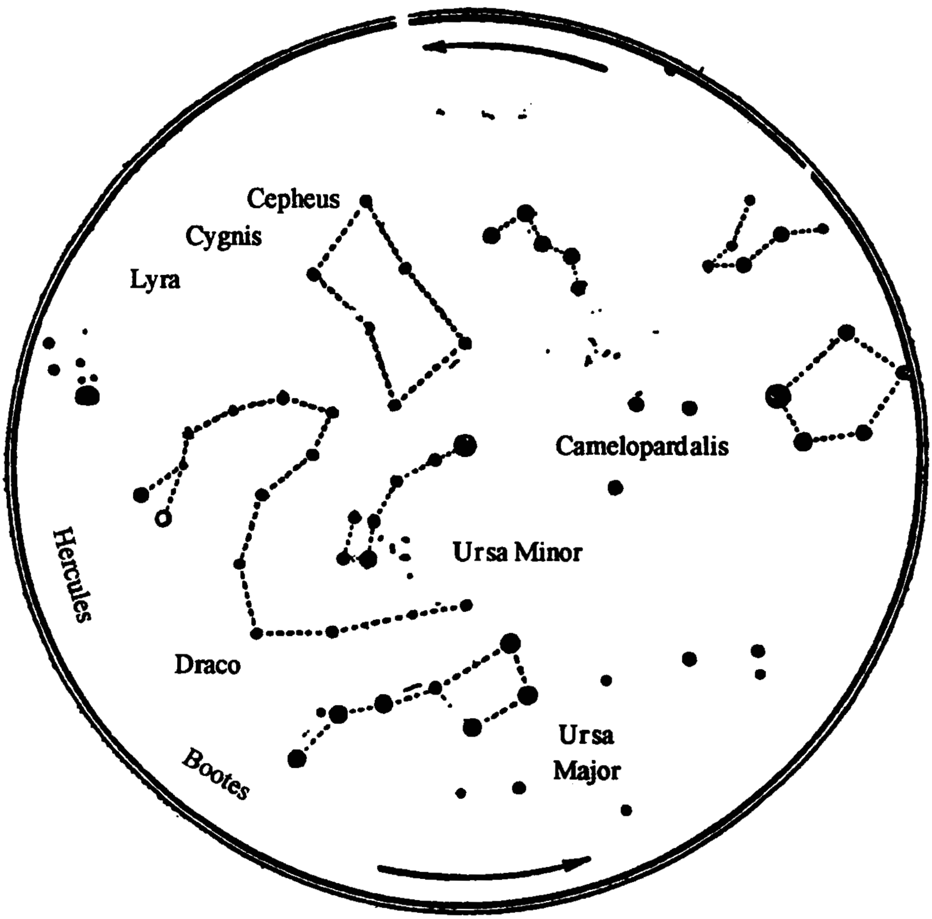

Figure 1 The present conception of the circumpolar constellations. From B. W. Vorontsov-Veljaminov, 1958, Astronomy (in Russian).

configuration: Ursa Major, Cassiopea, Pegasus and a few others. However, it is first of all the ecliptic that gives contrary examples. Pisces with its vast area does not contain stars that are brighter than the fourth magnitude. Another vast constellation – Aquarius – does not include stars brighter than the third magnitude. Nor are there bright stars in Sagittarius.

These facts support the view that ancient observers had been trying to solve not only the problem of uniting bright starry groups into the constellations (starry pictures) but also the problem of fixing certain important areas of the celestial sphere (space marks)."

Gurshtein argues that such objects, in particular, are Zodiac constellations.

As was announced in the work (Kaurov, 1996), the Draco constellation is a like object. Here further this is argued in detail.

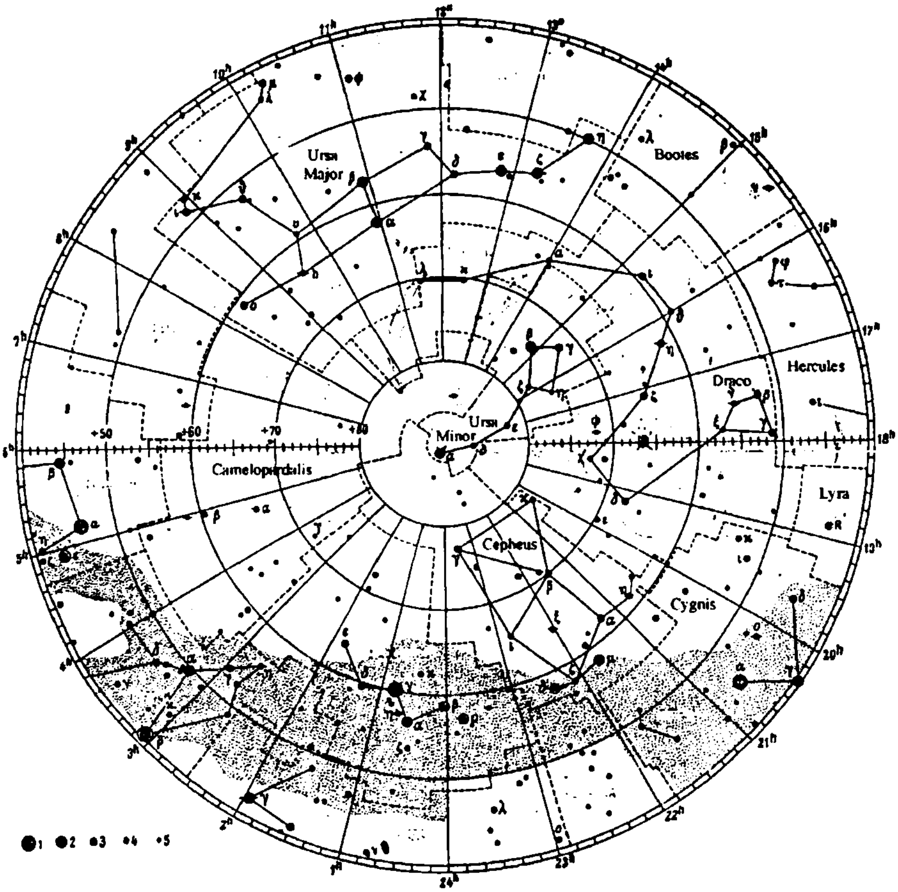

Figure 2 The Draco constellation among adjacent constellations of Hercules, Bootes, Ursa Major, Ursa Minor, Cepheus, Lyra, Camelopardalis and Cygnis. From Kulikovsky, 1961.

4 THE DRACO CONSTELLATION: ASTRONOMICAL INFORMATION

The Draco constellation (Figure 1) is one of the 88 constellations in the celestial sphere which was declared at the first General Assembly of the International Astronomical Union (IAU) in 1922. At this meeting a nomenclature of constellations was declared as the aggregate of sections of the celestial sphere, but not groups of some stars. The established boundaries of constellations differed very little from ancient ones. They were defined by means of accordance of its lines of boundaries with the sky circles of altitudes and meridians according epoch of 1875.

According to an established order, the Draco constellation has boundaries with constellations of Hercules, Bootes, Ursa Major, Ursa Minor, Cepheus, Lyra, Camelopardalis and Cygnis (Figure 2).

Figure 3 The Aratus conception of the circumpolar constellations. The Northen Hemisphere constellations after Eratosthenes. Reproduced from Schaubach's edition of the Catasterismi by Buhle, Leipzig 1801. (From Gurshtein, 1993.)

The Draco constellations has at least two remarkable peculiarities.

First of all, at the same centre of the constellation is situated the North Pole of the ecliptic ($\alpha = 18^h$, $\delta = 66.^\circ5$) (Kulikovsky, 1961).

Secondly, near the "tail" of the "figure" of Draco is situated a North celestial Pole, marked by Polar stars (α U Mi).

The size of the Draco constellation is about 1063 square degrees. Such a description (by means of the size criterion) makes them likely Zodiacal constellations of the first four – the quartet of Gemini, having a date of origin (according to Gurshtein, 1993), far beyond the sixth millenium BC.

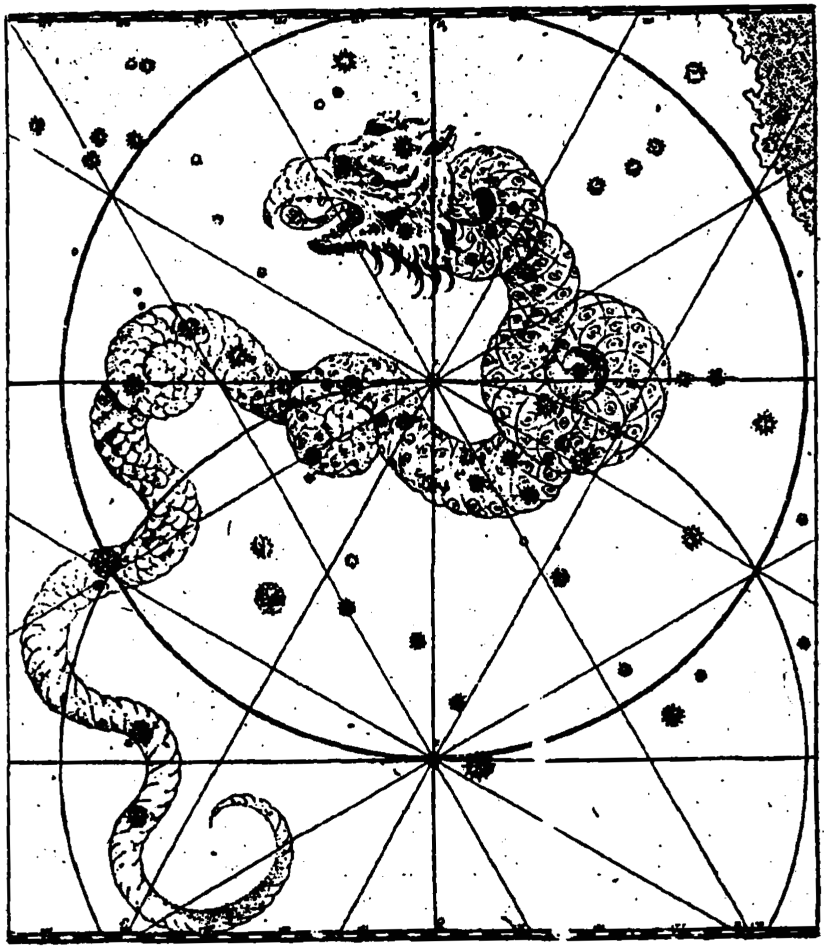

Figure 4 The Draco constellation. The picture from C. Flammarion "A History of the Sky" (1875) (reprinted from "Uranometry" of Bayer).

The Draco constellation has 80 stars (not less than $6\overset{m}{.}0$), but the brightest of them, γ Dra, has only $2\overset{m}{.}22$ (Kulikovsky, 1961). That is why, curving a comparatively narrow band between constellations Ursa Major and Ursa Minor (a mean width of a band is about five degrees here), the Draco constellation is almost invisible among the circumpolar constellations.

5 A COMPARATIVE HISTORY OF THE DRACO CONSTELLATION

The evidently historical information on the Draco constellation is there in Sumero–Akkadian and also into Greek relics of written language.

Ancient Greece. A desription of the Draco constellation is in a poem entitled "Phaenomena" written by Aratus in 275 BC (Germanicus, 1988), based on the manuscripts of "The mirror" and "Phaenomena", being created by an ancient astronomer and mathematician Eudoxus of Cnidos (Greece; 408–355 BC). It is supposed that he composed the first chart of the starry sky, where the constellations were images of various figures (Figure 3) and the stars were shown too, (see Kolchinsky *et al.*, 1977), Eudoxus first listed the names of Zodiacal and non-zodiacal constellations.

The Draco constellation is also present in the oldest star catalogue of Ptolomy named "Almagest" (second century AD). The last star, listed by Ptolomey, was λ Dra (the called "the end of the Draco tail"); this position of the "tail" conforms to the description that was given by Aratus.

Descriptions of Aratus and Ptolomey were still used by astronomers of medieval Europe (Figure 4).

Summer. According to van der Waerden (van der Waerden, 1991) a record of Draco constellation is there in the old Babyloninian prayer (1830–1520 BC). This prayer was used for a much older practice of foretelling the future. According to Saplin (1994), the name of the Draco cinstellation sounded ronghly like "The Yoke of the Sky" (summer MU. SIR. KES. DA). But the Draco constellation is uncertainly identifed in this case, because, in addition to the Draco constellation, there is also the "Yoke" constellation in the text of the refer old Babylonian prayer referred to.

Ancient Egypt. The liberties taken by the ancient Egyptians in arranging their sky figures are easily seen by examining the unfinished tomb of the nobleman Senmut (about 1473 BC). Its ceiling displays an astronomical representation that is the oldest work of its kind. Here stands a fantastic array of figures: hippo, man, lion, crocodile and others. Strikingly, the crocodile can be seen in two versions: a finished pose next to the smiting man's fist, and an ealier sketch, barely peeking through, showing the crocodile in a horizontal pose. In other words, the artist chose a symbolic representation, not a detiled mapping of the sky.

The Egyptian sky can be divided into two main sections. The northern constellations are those north of the ecliptic, or possibly north of the Milky Way. The southern constellations include the series of timekeeping decans that have given rise to our 24-hour division of the day. According to the monumental "Egyptian Astronomical Texts" of O. Neugebauer and Richard A. Parker, only three ancient Egyptian configurations can be identified with any certainty: the Big Dipper, shown as the foreleg of a bull and named Meskhetiu; Sirius, represented as the goddess Isis; and Orion, represented as the god Osiris.

Of all of the modern Egyptologists who have probed the problems of these ancient depictions, Virginia Lee Davis has perhaps been the most successful and certainly the most ingenious. She argues, both the Big and Little Dippers could be the celestial adzes chasing each other around the celestial pole (which was on Draco 4000 years ago), and the falcon-headed man could be Draco with Ursa Minor, the Little Dipper.

Nikolov and Charlampiev (1992) think that part of the Draco constellation was called the crocodile.

Ancient China. The Draco constellation is not recognized in the depiction given by Ssuma Chhien (1986) but in his work the sign of Draco was used for the marking of two of the five "sky palaces" (five regions of celestial sphere) dividing the starry sky of the ancient China of the Han age.

6 THE POLAR AND EQUATORIAL CHARACTER OF ANCIENT CHINESE ASTRONOMY

This and the following two points mainly follow the point of view of Needham (Ronen, 1981).

It is now established that ancient Chinese astronomy was based upon a system quite different from that of the Egyptians and Greeks, though in no way less logical or useful.

The Chinese, adopted the method of opposability, finding which stars lay opposite to the sun. This they achieved by concentrating their attention on the celestial pole and the constellations around it – the circumpolar constellations, which never rise and set, but are always above the horizon. Their system was therefore intimately assosiated with the meridian. They observed systematically, noting the times when the circumpolar constellations culminated or achieved lower transit.

The Greeks, of course, knew of the circumpolar constellations – Homer refers to them – and there is even a Greek story that the sentinels at the siege of Troy changed their guard according to the vertical or horizontal position of the tail of the Great Bear. There are, conversely, indications that some heliacal risings and settings were noted by the ancient Chinese. But the emphasis in China was quite different from that in Greece. The pole was the fundamental basis of ancient Chinese astronomy, and was connected with a background of thinking about the microcosm and the macrocosm, the correspondence between man and the universe. Thus the celestial pole corresponded to the emperor on earth, around whom the vast system of a bureaucratic agrarian state naturally and spontaneously revolved.

And during the first millenium BC, the Chinese built up a complete system of equatorial divisions, defined by the points at which the hour-circles cut the equator; these were the 28 hsiu or "lunar mansions". One has to think of them as segments of the celestial sphere bounded by hour-circles and named by the constellations which provided the stars lying on these hour-circles, and from which the unequal number of degress in each hsiu could be counted.

Circumpolar stars and equatorial mark-points

That the Chinese did key the invisible hsiu to the transit of circumpolar stars may be illustrated most clearly from the "Celestial Officials" chapter of the first-century BC Shih Chi (Historical Records). Ssuma Chhien says:

Piao is attached to the Dragon's Horn (Chio; hsiu No. 1). Heng hits the Southern Dipper (Nan Tou; hsiu No. 8) in the middle. Khuei is pillowed on the head of Orion

(Shen; hsiu No. 21). The dusk indicators (those of which transits are noted at dusk) are the Piao stars. The midnight indicator (the star of which the midnight transit is noted) is Heng. The dawn indicators (those whose transits are noted dawn) are Khuei stars.

The first sentence explains that Chio (our α Virginis; Spica) can be found from the last two stars of the handle. The next sentence states that a line from Yu heng (ε U Ma) parallel with that between Thien Chi (γ U Ma) and Thien chhuan (δ U Ma) will indicate the position of Nan Tou (our φ Sagittarius). And the prolongation of the "top" and "botton" of the bowl (i.e. γ and β U Ma, and δ and α UMa), will give lines meeting in Shen (Orion).

Therefore, having once gained a clear understanding of the daily rotation of the heavens, then the culminations and lower transits of the circumpolar stars would fix the position of every point on the celestial equator. Hence the position of the sun among the stars could be known; solar and stellar coordinates could be combined.

7 THE POLE AND THE POLE STARS

The basic importance of the celestial pole for Chinese astronomy has by now been made clear. But the effect of precession of the equinoxes on the position of the pole is considerable.

At present moving nearly in a circle around the pole of the ecliptic., the celestial pole is closed to Polaris (α U Mi), the Pole Star of contemporary astronomy. But in 3000 BC it was close to Thuban (α Draconis). It is therefore a fact of the greatest interest, as Needham states, that we find, along the whole length of the path it has traversed since that date, stars which have preserved the Chinese names indicating that they were at various times pole-stars, but later ceased to be so.

Investigation shows that the Chinese had a zone around the present Pole Star which was bounded by two "barriers" of stars, enclosing the "Purple Forbidden Enclosure" (an analogy with the imperial court). And the significant point is that on each side of the space, the end stars on one side were called the "Left Pivot", and on the other the "Right Pivot". Precisely between them lies the point which the celestial pole occupied about 3000 BC. Nearby, furthermore, are two stars in Draco – the "Celestial Unique" and the "Great Unique" – both of which are given on the thirteenth-century planisphere. They are dim stars, and, as Needham supposes, might have been considered pole-stars in the earlier and later part of the second millennium BC. Admittedly, as Needham supposes, they are not very close to the path of the celestial pole, but they are almost as close as the "Celestial Emperor" (Kochab or β U Mi) which it seems was used about 1000 BC. Ursa Minor was not a constellation recognised by the Chinese. Instead they used only two brighter stars of this constellation, together with some dim ones and one from the adjoining constellation Camelopardalis (4339 Camelopardalis). The star from Camelopardalis was the Pole Star of the Han.

8 THE DRACO CONSTELLATION AND THE ANCIENT CHINESE OBSERVATIONS OF THE SHIFTING POLE

It is evident that ancient Chinese astronomers observed the pole moving along the "tail of Draco".

With the passage of time, precession also brings about changes in the right ascensions of stars. This will affect the keying of the hsiu to circumpolar stars, and there seems to be evidence that this did indeed happen. For instance, the bright Chhien niu (the Herd-boy, our Altair) was later replaced by the dimmer Nu (e Aquarii), while Chih nu (the Weaving girl, our Vega) gave place to the weak Niu (β Capricornii). Again Ta chio (Arcturus), which may have been one of the stars from Bootes which earlier formed part of the handle of the Plough (i.e. seven of the brigther stars of the Great Bear) seems to have been replaced by Chio (Spica).

There is, however, another point. The positions of the hsiu Mao and Fang at opposite equinoxes would have been shared, at a different time, by Shen (Orion) and Hsin (Scorpio), and this raises the question of the meaning of the important word chhen (Figure 5*a*), which constantly occurs in ancient texts. In later usage it

Figure 5

acquired many meanings; besides being one of the twelwe cyclical characters used in a fortune-telling system linked to the calendar, it came to be used as one of the terms for the twelve standard double-hours, for auspicious or inauspicious conjuctions (close approaches) of celestial bodies, for lucky or unlucky stars, and for any definite time or monument. Sometimes the Three Chhen were spoken of, sometimes the Twelve Chhen. Needham suggested that the most ancient forms of the character represent the tail of a scorpion or a dragon (Figure 5*b*) and that the graph should be regarded as a drawing of part of the constellation Scorpio. This would explain, as assumes Needham, the significance of a passage in one of the ancient commentaries on the Chhun Chhiu (Spring and Autumn Annals) where the Great Chhen are defined as Ta Huo (Antares or α Scorii, the central star of Hsin), Fa (the sword of Orion, Shen), and the Pole Star (Pei Chi). The ancient meaning of chhen would thus be "celestial mark-point". As supposes Needham, here again we find the texts, and even the structure of the character, referring back to a celestial situation ealier than 2000 BC.

Then, it is to discuss the third point in addition to the two previous discussed by Needham. As precession brings about changes of the right ascensions of stars and the positions of one of the hsiu situated at opposite equinoxes would have been shared, at a different time, by the other of them, then the only constant element of Great Chhen is the "tail of the dragon", i.e. the shifting "tail" of the Draco constellation, where, at a different time the Polar Star is situated, the initial point of the ancient Chinese system of finding the position of the important cardinal point by deducing the positions of unobservable bodies from those of observable ones, all being firmly held in a network of coordinates based on the celestial poles and celestial equator.

Therefore it is naturally supposed that this term "chhen" also in more ancient times corresponded to the changing tail of the Draco constellation (see Figures 4 and 5*b*).

There are some more important facts about what the Draco constellation was recognized as by ancient Chiense astronomers.

Some ancient Chinese sacrifical bronze vessels are marked by "archaic hieroglyphic symbols (Karapetjanz, 1972), that are as an entire one" and in some important details are like those on the ancient pictures of the Draco constellation.

Furthermore, the symbol of the dragon having been associated with the name of Huang-Ti (legendary Yellow Emperor) was the marker (Yellow Dragon) of a central "palace" of ancient Chinese cosmography (Lukjanov, 1992).

The starry imagination of Huang-Ti is there in the determination of the asterism of the Suan-Yuan (a common group of some stars of the modern constellations of Leo and Linx). (Ssuma Chhien, 1986).

The Suan-Yuan is the generation name of Huang-Ti.

The drawing of the star group of Suan-Yuan had a very great likeness with the ancient picture of the Draco constellation, which therefore could be used in the central palace of the heavans that corresponded to the Polar Star.

Ssuma Chhien wrote in Shih Chi: "Stars of the chhuan are (a group of stars) of the Suan-Yuan resembling the body of a Yellow Dragon".

The conclusion is there that the ancient Chinese astronomers used an idea and symbol of the Draco constellation as a marker of the shifting pole during the entire history of their asnronomical observations. Let us determine this statement as the Draco constellation hypothesis.

9 THE EXAMINATION OF THE DRACO CONSTELLATION HYPOTHESIS BY USING AN ASTRONOMICAL DATA

First of all, the ancient image of the Draco constellation as a pole-marker should be reconstructed, taking into account the ancient constancy of traditions. Supposing the picture of the Draco constellation also has the same enduring traditions as the picture of the Zodiacal constellations (Gurshtein, 1993) take the list of the Draco constellation given by the Ptolomy star catalogue (see Table 1) (Peters, 1915).

The stars of this might be linked consequently in order of the Ptolomy list. As a result, drawing the scheme of the Draco constellation, we obtain the picture (Fi-

Table 1. Ptolemy's Catalogue of Stars. *Ctalogue II* – continued

No. in Baily	*Ptolemy's Catalogue*				*Modern name*	*Computed for A. D. 100.*		*Magnitude in Harvard Revised Photometry*	*C–Pt.*	
	No.	*Long.*	*Lat.*	*Mag.*		*Long.*	*Lat.*		Δ *Long.*	Δ *Lat.*
		DRACO								
44	1	206 40	+76 00	4	21 μ...	208 0	+76 27	5.8	+80	−3
45	2	221 50	78 00	4–3	$\left\{ \begin{matrix} 24 \\ 25 \end{matrix} \right\} \nu$...	223 9	78 21	4.2	+79	−3
46	3	223 10	75 00	3	23 β...	225 16	75 31	3.0	+126	−3
47	4	237 20	80 00	4	32 ξ...	237 47	80 30	3.9	+27	+10
48	5	239 40	75 00	3	33 γ...	241 32	75 12	2.4	+112	−18
49	6	264 40	82 00	4	39 b...	266 34	82 0	4.8	+114	−20
50	7	272 20	78 00	4	46 c...	274 7	78 6	5.1	+107	−9
51	8	268 50	80 00	4	45 d...	269 53	80 1	4.9	+63	−19
52	9	289 30	81 00	4	47 o...	289 26	81 0	4.8	−4	−10
53	10	338 0	81 00	4	58 π...	338 44	81 48	4.6	+44	+3
54	11	350 30	83 00	4	57 δ...	352 26	82 51	3.2	+116	−9
55	12	7 40	78 00	4	63 ϵ...	7 22	79 23	4.0	−18	+33
56	13	352 50	77 00	4	67 ρ...	355 12	78 5	4.7	+142	+15
57	14	10 40	80 00	5	61 σ...	11 36	80 51	4.8	+56	+21
58	15	21 40	81 00	5	52 ν...	25 18	83 3	4.9	+218	+83
59	16	26 10	80 00	5	60 τ...	28 59	80 27	4.6	+169	+12
60	17	73 20	84 00	4	31 ψ...	76 27	83 48	4.9	+187	−42
61	18	50 20	83 00	4	44 χ...	52 46	83 13	3.7	+146	−17
62	19	41 50	84 00	4	43 φ...	45 33	84 38	4.2	+223	−12
63	20	118 40	87 00	6	27 f...	116 58	86 47	5.2	−102	−43
64	21	111 40	86 00	6	28 ω...	104 45	86 49	4.9	−415	−1
65	22	159 0	81 00	5	18 g...	156 3	81 39	5.0	−177	+24
66	23	159 20	83 00	5	19 h...	156 2	83 12	4.8	−198	+12
67	24	158 20	84 00	3	22 ζ...	154 9	84 47	3.2	−251	−3
68	25	160 0	78 00	3	14 η...	167 1	78 30	2.9	+421	+30
69	26	163 0	74 40	4–3	13 θ...	170 12	74 31	4.1	+432	−9
70	27	162 40	70 0	3	12 ι...	157 48	71 7	3.5	−292	+67
71	28	127 20	64 40	4	10 i...	127 58	65 16	4.8	+38	+36
72	29	131 10	65 30	3	11 α...	130 32	66 17	3.6	−38	+47
73	30	109 10	61 15	3	5 κ...	109 31	61 37	3.9	+21	+22
74	31	103 10	+56 15	3	1 λ...	103 39	+57 4	4.1	+29	+49
Polar angle $\Delta = \pi/2 -$ Lat.									+5.0	±254

Note. The latitude of the Draco stars is equal to the difference between $\pi/2$ and the polar angle of the Draco stars into the picture of the figure of the Draco constellation (see Figure 6).

gure 6). A similar picture was given by Flammarion (1875) (Figure 7). Now we use the global astronomical data taking into account the curve of deviation of a local temperature (ΔT) at the time (t) snow precipitated onto the surface of the ice sheet of the south polar region of the earth during the last 150 000 years (Kotljakov, 1994).

Assuming an aproximately linear relation between the angle of declination of a pole axis and a local zone temperature of the south pole region let us bring the dependence of the declination at the time to conformity with the function of the lo-

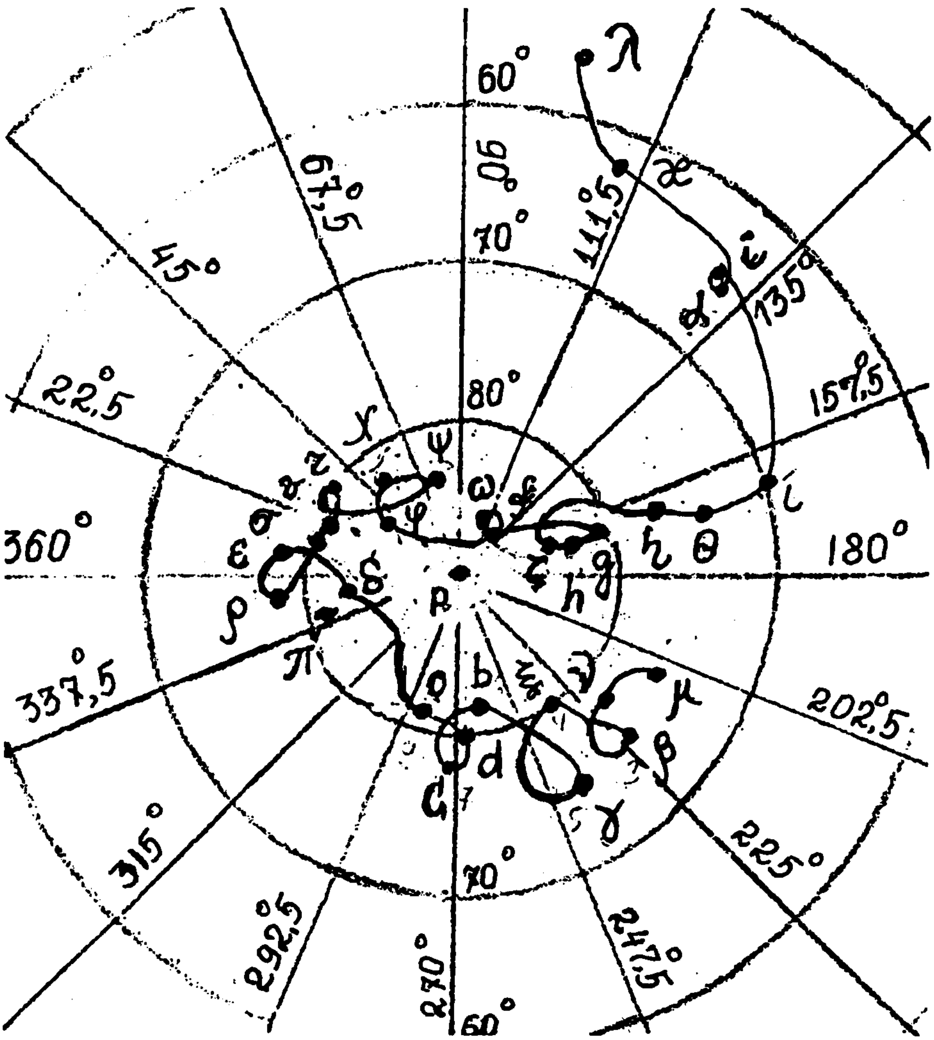

Figure 6 The Draco constellation by the list of the Draco constellation from Ptolemy's Catalogue of Stars (see Table 1). The ecliptic system of coordinaters. The pole of the ecliptic is in the centre (P).

cal polar temperature at that time. It may be done taking into account the approximately linear relation between a zone latitude temperature and a zone latitude that was obviously successful (Monin, 1972).

To obtain the best conformity between the discrete positions of the sequential stars of the Draco constellation and a curve of a local temperature of snow onto the polar surface, we take into account the long-time trends of a mean quantity both for a temperature curve and a scheme (see Figure 6) for the Draco constellation (the declination and a polar angle Δ, see Table 1).

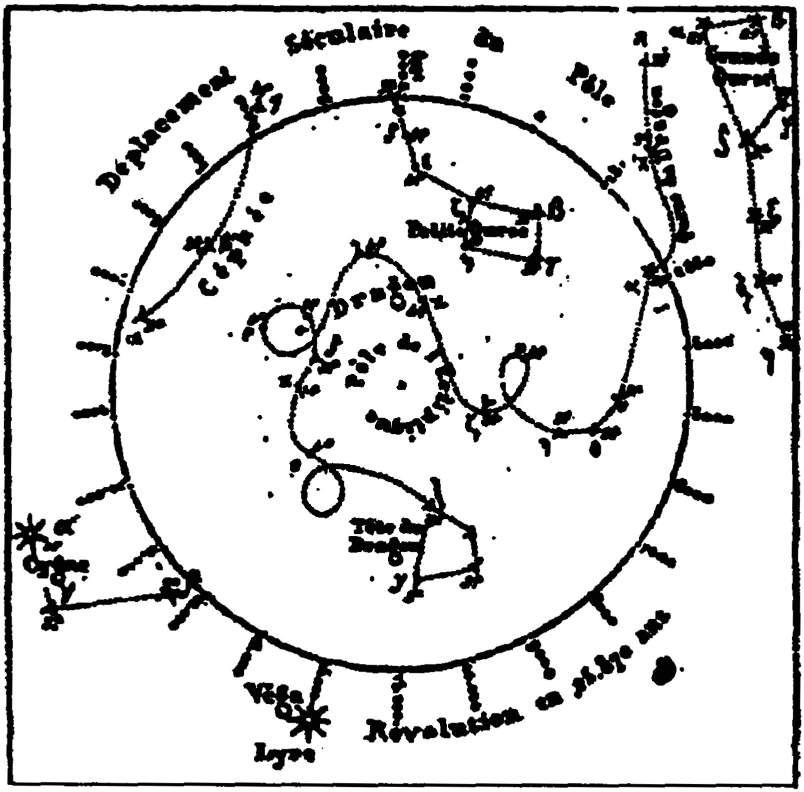

Figure 7 The Draco constellation by C. Flammarion "A History of the Sky".

As a result we obtain the discrete position of the sequence of stars into the graph of the temperature curve (see Figure 8, where mark-points of the stars of the Draco constellation marked as (–)).

According to this result the age of the Draco constellation may be preliminarily estimated as approximately 110 000 years.

10 THE POSSIBILITY OF THE EXISTENCE OF THE DERIVED REGIME OF THE MOTION OF THE AXIS OF THE EARTH

Using the equations (7.3.17) (Beletsky, 1975) for the lunar-sun precession of the axis of the earth we obtain after a simple transform

$$\begin{aligned}\dot{\Delta} &= -\varepsilon K_g^{\text{☾}} \cos\Delta \cos(\alpha - K_{\Omega}\tau) + O(\varepsilon^2)\\ \dot{\alpha} &= 2(K_g^{\odot} + K_g^{\text{☾}})\cos\Delta + \varepsilon K_g^{\text{☾}} \frac{\cos 2\Delta}{\sin\Delta}\sin(\alpha - K_{\Omega}\tau) + O(\varepsilon^2),\end{aligned}$$

where Δ is a polar angle between the pole of the ecliptics and the celestial pole; $\Delta = \pi/2 - \text{Lat}$ (see Table 1 and Figure 6), α is the right ascension of the vector of

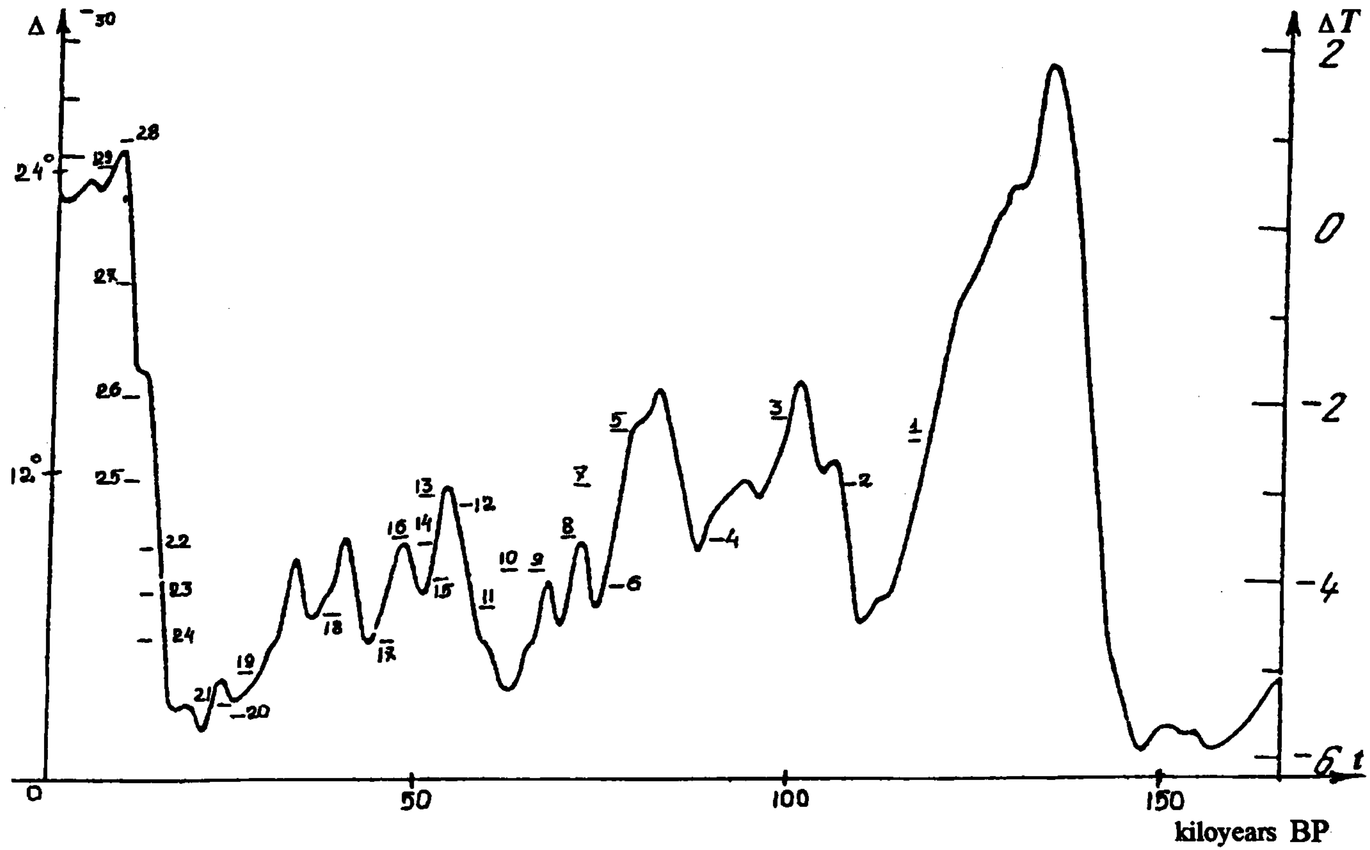

Figure 8 The temperature curve at the time snow precipitated onto the surface of the ice sheet of the south polar region of the earth during the last 150 000 years (see Kotljakov, 1994). A scale unit of one degree of temperature (ΔT).

the angular momentum of the revolution of the earth; $K_g^{\odot}$, $K_g^{☾}$, K_{Ω} are constants, ε is a small value.

Introducing the notation

$$2(K_g^{\odot} + K_g^{☾}) = K_\alpha,$$
$$\varepsilon K_g^{☾} = K_\Delta,$$

and neglecting $O(\varepsilon^2)$, carry out an rough analysis of the possible resonace regime of motion.

First integral is

$$\sin\beta = \frac{1}{\sin 2\Delta}\left(C + \frac{K_\alpha}{2K_\Delta}\cos 2\Delta - \frac{2K_\Omega}{K_\Delta}\cos\Delta\right)$$

where $\beta = \alpha + K_\Omega\tau$; C - const.

Let us assume

$$\alpha - K_\Omega\tau \simeq \delta\tau,$$
$$\dot\alpha - K_\Omega \simeq \delta,$$

where δ is a small negative value in the region of the resonance.

Assuming also that

$$\Delta \leq \Delta_0 = 24^\circ,$$

then $\dot\Delta = -K_\Delta\cos\Delta\cos\delta\tau$.

From this, taking into account

$$\delta\tau < \Delta$$

we obtain

$$\sin\Delta \simeq -K_\Delta\cos\delta\tau,$$

and then

$$\sin\Delta \sim \sin\Delta_0 - K_\Delta\frac{\sin\delta\tau}{\delta}.$$

Taking into account

$$\sin\delta\tau \sim \delta\tau,$$

we obtain

$$\sin\Delta = \sin\Delta_0 - K_\Delta\tau. \qquad \text{(A)}$$

Then

$$\dot\alpha = K_\alpha\cos\Delta + K_\Delta\frac{\cos 2\Delta}{\sin\Delta}\delta\tau$$

and taking into account $\Delta < 24^\circ$, assuming $\cos\Delta \sim 1$, $\cos 2\Delta \sim 1$ when Δ are small we obtain

$$\dot\alpha \simeq K_\alpha + K_\Delta\frac{\delta\tau}{\sin\Delta_0 - K_\Delta\tau},$$

where $\delta < 0$.

It may be concluded then that Δ decreases from Δ_0 to 0, when $\dot{\alpha}$ is first positive, then 0, and finally has negative values.

Thus we obtain the description of the regime like the one that we have from the analysis of the figure of the Draco constellation.

The numerical estimation of the time interval of the decrease of an angle Δ from 24° to 0° give us by the calculation using (A) of 30 000 years. The estimation from a temperature function (Figure 8) immediately gives us about 100 000 years.

But the first estimate was made for an aperiodic, but not an oscillatory real regime and in fact it represents, therefore, a lower bound, i.e. a satisfactory lower estimate.

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