A Sky Dome Visualisation for Identification of Astronomical Orientations

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Figure 1: Virtual reconstruction of a look through one of the doors in the neolithic *Kreisgrabenanlage* of Steinabrunn in Lower Austria. The singular post appears to be aligned to the rising point of the Pleiades star cluster, which with their rising in the morning shortly after spring equinox possibly announced the beginning of the agricultural year. Astronomical alignments like this have been identified using the method described in this paper. Screenshot from StarryNight Pro 4.5, foreground from virtual reconstruction courtesy of Imagination Computer Services, Vienna.

Abstract

It has long been known that ancient temples were frequently oriented along the cardinal directions or to certain points along the horizon where the Sun or the Moon rises or sets on special days of the year. In the last decades, archaeologists have found evidence of even older building structures buried in the soil, with doorways that also appear to have distinct orientations.

This paper presents a novel diagram combining archaeological maps with a folded-apart, flattened view of the whole sky, showing the local horizon and the daily paths of the Sun, Moon and brighter stars. By use of this diagram, interesting groupings of astronomical orientation directions, e.g. to certain sunrise and sunset points could be identified, which were evidently used to mark certain days of the year. Orientations towards rising and setting points of a few significant stars very likely indicated the beginning of the agricultural year in the middle neolithic period.

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1 Introduction

A large body of evidence shows the connection of ancient cultures to annually repeating celestial events. In many old cultures, temple axes are typically aligned either along cardinal directions (e.g., the Pyramids in Egypt are the most popular and best studied example) or towards solstitial risings and settings of the sun, e.g. Persepolis [1]. Another frequently cited example is Stonehenge and many other megalithic sites, which were presumably overinterpreted by various authors, most notably Thom [2], but are largely accepted as sun- and moon-oriented temples [3]. Also medieval churches were frequently oriented towards the rising point of the Sun on the day of the church's patron [4], while Muslim mosques (at least their interior) must be geographically oriented towards Mecca.

Apparently the orientation of buildings has a much older tradition. Since the 1960s, systematic aerial photography, later combined with geomagnetic prospection with highly sensitive caesium magnetometers and, where possible, successive excavations, discovered a certain class of neolithic circular *enclosures*: *Kreisgrabenanlagen* (KGA). They typically consisted of 1–3 nearly circular wooden palisade walls, surrounded by 1–3 ditches, which were V-shaped and up to 6m deep and 12m wide. The circular ditches were broken by "earth bridges", which allowed people to enter the *enclosure* through gaps ("doors") in the palisades. The

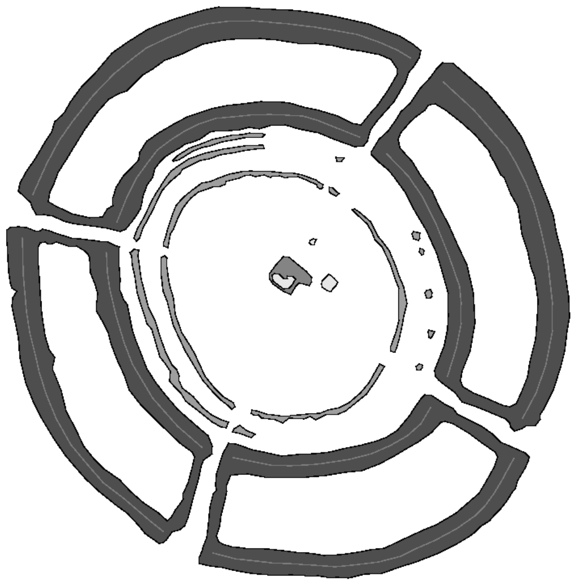

Figure 2: Archaeological map of the *Kreisgrabenanlage* (KGA) Steinabrunn in Lower Austria [5]. The wide brown rings indicate the circular ditches which are connected by narrower radial ditches along 4 access bridges. In the central area, traces of 3 concentric palisade walls are marked in a lighter shade of brown. Small brown dots indicate singular postholes, the green area marks a central pit. A multitude of similar KGA traces has been found in the last decades, among the many theories about their use exists the idea of astronomically oriented doorways.

overall diameter of these *Kreisgrabenanlagen* is approximately 40–180m. The best archaeological survey results, short of the slow and very costly direct excavation, come from measuring the minute deviations of the Earth's natural magnetic field caused by the different qualities of soil which today fill the ditches. According to ^{14}C dating of excavated bone material, all KGAs have been erected in the very short time span between 4800 and 4500 B.C. These structures have been found over a large part of central Europe, from Hungary to northern Germany, with a concentration of over 40 such structures known in Lower Austria (e.g., Figure 2).

Since the 1980s, with increasing numbers of known KGAs, theories about their use have been discussed and rejected, spanning from cattle paddocks to fortifications. The current interpretation is their use as a place for special gatherings, cultic worship, or initiations. But, in parallel to the much younger megalithic constructions of Great Britain and Brittany [6], also some astronomical alignments have been proposed, most notably by Becker [7], who found that *Kreisgrabenanlagen* of Bavaria had doors and access bridges aligned to rising or setting points of the Sun at the solstices.

During the preparation of the first large public exhibition on *Kreisgrabenanlagen*, the theory of astronomical connections has also been investigated. This paper describes what has to be taken into account for these orientation studies. Not only possible Sun-related directions have been studied, but also Moon- and star-related directions. A key element on the way to an interesting discovery has been a diagram combining the archaeological map with a celestial map, which allows the immediate identification of possible alignments.

This paper extends a previous paper [8] in the following sections: In section 2 some astronomical issues are described in more detail than before. In section 3, more related work in the field of archaeo-astronomy is cited and examples of radial mappings in geographical maps are given. The diagram itself has been developed further to better display features along the horizon and the diurnal arcs of the Sun and the Moon (Section 3.4.1). Also, a version of the diagram showing interesting lines which have been derived from the Sun's positions, and which could be of interest for investigations for a wide range of possible solar alignments, is presented in section 3.4.2. Some impressions from users (the archeologists) are given in section 4.1.

The rest of the paper is as follows: first, important terms from astronomical phenomenology are defined, and necessary astronomical computations are pointed out. Next, some examples of radial mappings in geographical maps are given. Then, a methodology is developed which shows how to apply various diagrams to questions related to astronomical orientations. *Kreisgrabenanlagen* are used as example, but the same idea can be and has been [9] applied to any building or geological structure for which an oriented map exists. Then a combined result from a multitude of KGAs is shown, which allows the postulation of an archeoastronomical theory, which is described shortly.

2 Celestial Positions

To compute the position of a celestial object, we need

- the *geographical position* (λ, φ) of the observer, where the geographical longitude λ is positive for longitudes east of Greenwich and latitude φ is positive on the northern hemisphere,

- the object's *celestial coordinates* (α, δ) on the imaginary infinite celestial sphere, with the longitudinal coordinate α named *right ascension* and counted in hours instead of degrees, eastward from the *First Point of Aries* ♈. This point marks the one intersection of the celestial equator with the Sun's annual path, the *ecliptic*, where the Sun crosses the celestial equator northward, this event defining the beginning of astronomical spring in the northern hemisphere. The latitudinal coordinate δ is called *declination* and is positive for objects north of the celestial equator.

- the *time* of observation. Here we have to take care not to use just zone time (maybe even further denaturalized by daylight saving time), but *local mean solar time*.

From these data, we can compute an object's *azimuth A*, i.e., its horizontal direction, counted from north (0°) eastward (or, following a different, equally valid convention, from south westward), and *altitude a*. Details of the computation of positions can be found in general astronomical literature, e.g. [10].

On any day of the year, stars rise and set approximately 4 minutes earlier than on the day before. Stars surrounding the celestial pole of the observer's hemisphere are visible in every clear night and called *circumpolar*. Others are only visible during certain parts of the year, the Sun being too close to them to be observable at other times. The last time such a star is visible at dusk is called its *heliacal setting*. After a few weeks of invisibility due to close distance to the Sun, they emerge in the morning on the day of their *heliacal rising*: in the morning twilight, they appear shortly over the horizon haze, only to become too washed out a few moments later by the increasing brightness of the emerging daylight. On each successive day, they will be visible for about four minutes longer. It has long been known that heliacal risings have been used by various peoples all over the world to mark specific days of the year [3], the best known example being the Egyptian use of the heliacal rising of Sirius as "herald" of the Nile flood.

The rising and setting azimuths on a location's horizon depend on its geographical latitude φ, the star's declination δ and the local horizon's altitude. On the northern hemisphere, any elevation on the horizon will shift both rising and setting points southward.

Name	Constellation	mag	a_E
Arcturus	Bootes	-0.1	0°
Vega	Lyra	0.0	0°
Capella	Auriga	0.1	0°
Procyon	Canis Minor	0.4	0.3°
Altair	Aquila	0.8	0.7°
Antares	Scorpius	0.9	0.9°
Pollux	Gemini	1.2	1.2°
Deneb	Cygnus	1.3	1.3°

Table 1: Extinction angles a_E for a few stars[11, p.130].

In addition, for investigation of rising and setting alignments along the horizon, two phenomena caused by the Earth's atmosphere have to be taken into consideration:

refraction, causing a slight increase of apparent altitude for all celestial objects, most pronounced close to the horizon. Refraction also causes the Sun and Moon to appear vertically compressed when they are near the horizon, because their respective lower limbs will be raised more than their upper limbs, and raise both these objects by about $1/2$ degree on the horizon, thus causing also a slight northward shift in both rising and setting points. The correction R, in arcminutes, to be added to the geometrically computed altitude, amounts to

$$R = 0.0019279 + \frac{1.02}{\tan(h + \frac{10.3}{h+5.11})} \cdot \frac{P}{1010} \cdot \frac{283.15}{273.15+T} \quad (1)$$

where P is pressure in *mbar* and T temperature on the Celsius scale [10, p.106].

This shift also applies to stars, but only the very brightest stars are visible in so low altitudes, because of the

extinction, which reduces the objects' luminosities, usually making dimmer stars invisible near the horizon. A star's brightness is given on a logarithmic magnitude scale, the brightest stars having slightly negative numbers. The dimmest stars observable without optical aid under best conditions are about *mag* 6.5, but only close to the zenith. In low altitudes, esp. close to the horizon, the atmosphere absorbs much of the starlight. Only the brightest stars are visible on the horizon, most stars will not be visible below a certain altitude, their respective *extinction angle* a_E. Table 1 shows a few extinction angles for best conditions. Depending on humidity and dust, a_E can be larger.

For the Sun and the Moon, one more aspect can only be guessed: whether the alignment intended to point towards the point of first (respectively last) visibility (i.e., upper limb), disk center or full visibility (lower limb).

2.1 Sun

Mirroring Earth's motion around it, the Sun annually describes a great circle on the celestial sphere, which due to Earth's tilted axis intersects the celestial equator on the *First Points* of *Aries* ♈ and *Libra* ♎. The moments the Sun is at these points define the beginnings of astronomical spring and autumn, respectively, in the northern hemisphere. The Sun can reach northern and southern declinations equal to the Earth's axis tilt from orbit normal, which is currently about $\varepsilon = 23.5^\circ$, but slowly and slightly varies over millennia. Reflecting this, the annual points of sunrise and sunset span a wide arc along eastern and western horizons. Near the solstices ("standstills"), the Sun rises or sets on almost the same positions for several days.

It is known from older cultures [3] that some peoples defined the seasons not beginning with solstices and equinoxes, but centering the seasons around these dates, leading to terms like "midsummer" for summer solstice. Traces of this tradition survive in today's All Saints' Day/Halloween and Candlemas as start and end of Winter, and May Day as start of Summer.

2.2 Moon

Similar to the Sun, the Moon can reach a wide area of declinations. Due to its orbit being tilted about $i = 5^\circ$ from Earth's orbit, its extreme north and south declinations vary even wider, with outer extremes ("major standstills", $\delta = \varepsilon + i$) and inner extremes ("minor standstills", $\delta = \varepsilon - i$) [6]. Due to orbital motions, these extreme standstills occur in intervals of about 18.6 years [10].

2.3 Stars

Although called *fixed stars*, over the course of centuries and millennia, stars do change their position on the celestial sphere mostly due to

precession, a motion of Earth's axis counteracting the tug of Moon and Sun on Earth's equatorial bulge, which both attempt to erect Earth's rotational axis. Acting like a spinning top, Earth evades this erection by moving its axis sideways. This results in a motion where the Earth's axis over about 25800 years traces a double cone with the tip in the Earth's center. Reflecting this motion, the stars seem to move parallel to the ecliptic (the red line in figure 3), slowly changing their coordinates on the celestial sphere. For this reason, the star we now know as Pole Star will be far from the pole in just a few centuries, rendering it unusable for navigational purposes. The neolithic sky was shifted by about 90° from today's sky.

On the other hand, the stars'

proper motion in space is hardly noticeable even after several thousand years, due to their enormous distance from the Solar system, with only a handful of bright exceptions.

Meeus [10] describes algorithms to correct stellar catalog positions given for one epoch to another.

If a structure's age cannot be narrowed down to be within at most a few hundred years, searching for alignments with stars is useless, because almost every azimuth will be covered by some bright star rising or setting there at some point in time. In such cases, only solar and lunar alignments can be investigated.

Fortunately, the epoch where *Kreisgrabenanlagen* were in use is known and is even short enough to use a single mean date for all sites without too large errors. The effect of precession on declination δ (and thus, combined with latitude φ, on rising and setting points) will be strongest where the ecliptic crosses the equator. In the latitude of $\varphi = 48.5^\circ$, during the 300 year period, the maximum azimuth shift amounts to about 2.6°, meaning that working with an average date within the interesting period the values should not be much more than $\pm 1.3^\circ$ off. Lines inside the KGAs cannot meaningfully be given to sub-degree accuracy, because the exact positions of, e.g., post tops above the surface is lost and can only be estimated from post hole positions.

3 MAPPING THE SKY DOME

For archeo-astronomical research, a method has to be found to combine archeological data, e.g., an excavation map, with astronomical data, i.e., positional data of celestial objects. Research typically concentrates on alignments of artificial structures towards rising and setting points of the Sun, Moon and selected bright stars.

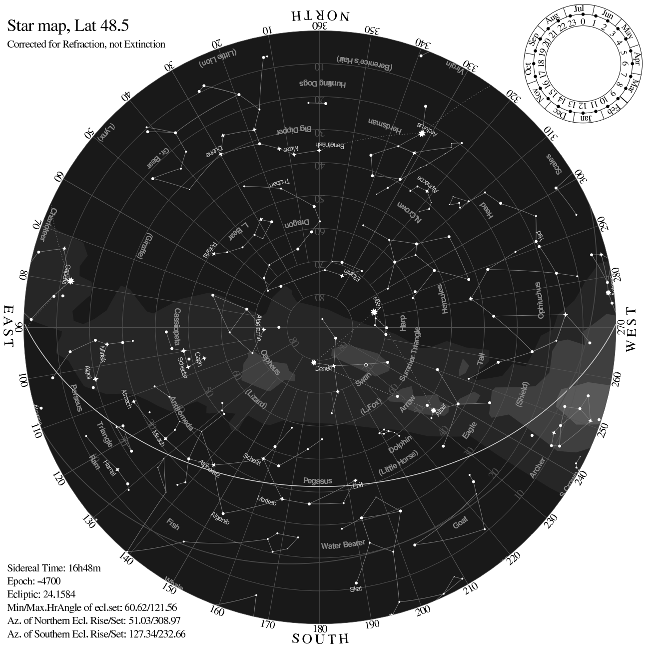

Figure 3: Typical all-sky map. When looking up from the Earth, cardinal directions appear mirrored compared to a geographical map. The red arc is part of the annual solar path, the *ecliptic*. The circle at upper right aligns mean solar time and calendar date to show when this map is applicable each day. The setting is for a situation in the year 4701 B.C. (astronomical -4700), described later in the text (Section 4).

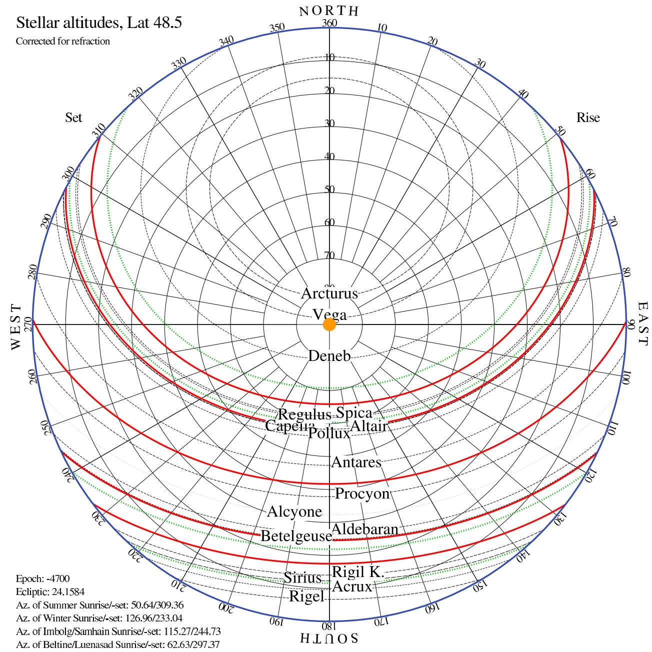

Figure 4: Map showing diurnal arcs (daily paths) of brighter stars over the sky, together with the Sun's diurnal arcs on 8 specific dates of the year (red) and extreme arcs of the Moon (green). The viewer is looking downward from the outside of the apparent sky dome, so the cardinal directions are aligned like on an ordinary geographical map. The stellar arcs change over centuries due to precession and (much less) stellar proper motion. Rising and setting directions can be read off at the horizon line (blue). Like in figure 3, the map is centered around the zenith (orange dot).

Earlier studies frequently just pointed out orientations towards these directions on a map, assuming a flat horizon, because surveyed horizon data was rarely available in archaeological studies, and data of rising and setting points for zero altitude (i.e., along the mathematical horizon) are easy to compute. The resulting plots typically resemble *starplots* [12, p.50] of the number of orientations vs. direction (azimuth). For example, Schlosser describes the change of orientation of burials in different stone-age cultures, where one group buried their dead in east-west orientation, another in north-south orientation [1, pp.72ff]. From such diagrams it is possible to see clear trends of burial orientations along the cardinal directions. However, in these diagrams and similar ones showing axes of megalithic buildings [11, p.114], a reader cannot follow authors' arguments in favour or against possible stellar alignments, because even if they are outlined in the diagram, it is not clear whether they point to the rising respectively setting point on the mathematical horizon or take into account the local horizon.

There exist a few examples of artistic geographical maps that combine local landscape with its respective horizon. A famous 1530 woodcut by Niklas Meldemann shows the first siege of Vienna (1529) by the Turks. The map is centered on St. Stephen's Cathedral in the city centre and shows the city buildings, the besiegers's tents and surrounding landscape almost as if seen from above through a fish-eye lens. Whichever way the map is turned, its upper part will show a panoramic view of the landscape in front of the viewer, who is thought situated above the city center. However, it shows the façade, not the roof of St. Stephen's Cathedral. The map is on display in Wien Museum in Vienna.

Much more recently, a radial panorama map has been published by the tourist board of the skiing resort of Obertauern (Austria) only several years ago. Again the center shows the central area, with ski slopes and lift systems radiating towards the map's borders, which show a panorama view of the surrounding mountains. Recent editions however seem to have returned to the traditional panorama map layout with the valley near the bottom and the panorama of the surrounding mountains near the top of the map, which seems more appropriate for simple online presentation.

Horizon profiles nowadays can be acquired from a Geographical Information System (GIS) including a Digital Elevation Model (DEM), so a diagram combining the archeological structure, sky dome and horizon could be created.

3.1 All-Sky Map

A common way to show an all-sky star map, sometimes found in newspaper columns, consists of a fisheye-like round star map of diameter $2r_0$ either in stereographic projection or with linearly mapped zenith distance (Figure 3). In the linear mapping, a point with azimuth A and altitude $a > 0$ on the hemisphere is mapped to a point with radius $r = r_0 \frac{90^\circ - a}{90^\circ}$ and angle $\theta = A$, counted counterclockwise from top. For the stereographic mapping (not shown here), $r = r_0 \frac{\cos a}{1+\sin a}$. The zenith in the center shows stars immediately overhead at a certain time, whereas the stars close to the outer border are low on the horizon. A grid helps to visually estimate azimuth and altitude of any object.

This mapping nicely shows an instantaneous view of the sky, but is almost totally useless for investigations of points on the horizon where the Sun or stars rise or set.

3.2 Star Path Map

Our interest while investigating astronomical alignments at first does not involve an instantaneous view, but a representation of all

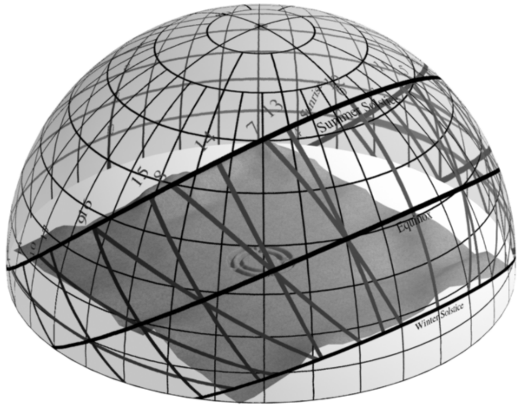

Figure 5: A mapping similar to Fig. 4 showing only the Sun's annual sky coverage used in a 3D scene, viewed from south-west. Mapped on an infinite sphere, a virtual walkthrough of an archaeological site will show possible alignments.

possible positions a star can reach for a certain geographical location. This leads to a map showing the *diurnal arcs* (daily paths) of the stars (Figure 4). In this figure, we exchanged east and west to provide a mapping which represents a view from "outside" the local sky dome, so east and west are oriented like on an ordinary geographical map, and $\theta = A$, but counted clockwise from top. This map allows us to read the rising and setting points of celestial objects on the outer border, and also the altitudes and combined azimuths an object can reach. Of course, the star trails must be computed taking refraction into account (eq. 1), so all rising and setting points will show a slight northward bend near the horizon.

In this map it can also be seen which stars pass close to the zenith (center of the map). Such stars may have played a significant role in the culture's mythology and star lore.

Such a mapping can be combined with fisheye photographs of the full sky dome so that nearby trees, houses etc. will be seen in the photographs. This combined image can be used to estimate hours of sunlight for any given place, which can be of interest for architects or real-estate agents, or planners of solar power plants, or even movie directors planning to shoot outdoor scenes [13].

3.2.1 Application for a 3D Scene

The map of figure 4 is perfectly usable as texture on a large (infinite, if possible) hemisphere for a virtual reconstruction inside a 3D modeling or VR application (Figure 5). During a virtual walkthrough of the scene inside the sky hemisphere, astronomical alignments can be identified. However, 3D reconstructions of archaeological sites including their surrounding landscapes require lots of effort, so a simpler way had to be found.

3.3 Flipped Star Path Map

The map of figure 4 is a valuable tool in itself, however, superimposing maps from archaeological sites (Figure 2) with it is difficult due to cluttering.

Our aim was to find a mapping in which the orientation lines (ditches, palisade gaps) can be combined with points on the horizon which in nature lie outside of the structure. To achieve this, we must leave the traditional mapping of the hemisphere to the circle with the zenith in the center. Instead, we flip the mapping by opening the sky dome at the zenith and "folding" the sky outward. This creates a map with an opening in the center, where we leave room for other data, and the whole sky flattened outward, with the point of the zenith mapped to the outermost circle. So, $\theta = A$, counted clockwise from north like on a geographical map, but $r = r_0 + sa$, where r_0 is the radius of the inner area and s some arbitrary scaling factor. The star paths appear largely unnatural at first but are still readable. Rising and setting points can be read again on the horizon, which is now the inner circle (Figure 6).

The red arcs in Figures 4 and 6 represent the Sun's paths at the dates of solstices (northern-/southernmost), equinoxes (east to west) and dates lying between these dates. Dashed green lines represent the standstill lines of the Moon. Star paths are marked in black arcs with various dot patterns according to the brightness of the respective star. The maps show star paths of the year 4701 B.C. (the astronomical year -4700).

This mapping now provides an inner area, which we used for two distinct purposes: Investigations of singular KGAs and an interpretation of a histogram of all identified directions.

3.3.1 Identification of Alignments

When the center of the map, which is the observer's position, is moved through the archaeological map, plausible alignments can be located. For a preliminary study, the diagram was simply printed on an overhead transparency and used with hardcopy prints of maps of the archaeological artifacts.

For more thorough investigations concerning phenomena on the horizon (rising, setting), a local horizon should and can be added, slightly shifting all rising and setting events southward (on the northern hemisphere). We used horizon data extracted from Geographical Information System (GIS) data. Not all radial lines in KGAs intersect in a common center, so loading the KGA map and flipped star map into separate layers of a graphical editor allowed shifting of the KGA map and thus selecting the exact observer position, which was usually still close to the center (Figure 7). Non-radial directions have been marked with their respective orientations, allowing the identification of the intended orientation from the star map.

3.3.2 Orientation Histogram

All plausible orientation lines (views over earth bridges, along radial ditches or through palisade gaps from viewpoints close to the center) of 28 *Kreisgrabenanlagen* were entered in a circular histogram placed inside the mapping from figure 6. This histogram, in combination with the star path map lying immediately outward, allowed us to identify groups of alignments which indicate that these directions had been chosen so that the objects rising or setting in these directions can be observed by looking e.g. along a ditch or through a door or gap in the palisade (Figure 8).

Note that this histogram only works if the horizons are not highly elevated and if all sites approximately share geographical latitude. Due to the fact that an elevated horizon shifts both rising and setting points southward (on the northern hemisphere), the peaks in the histogram are a bit widened, but *towards the south only*. The widening is greater along the northern and southern parts of the horizon, caused by the shallow angles of the diurnal arcs in these areas.

3.4 Improving the Diagram

3.4.1 Improved Horizon Readability

Given that the horizon is the most interesting region, it can be enhanced to use more space in the diagram. For this, the mapping of the sky has to be made nonlinear to allow the stretching of the horizon. For a recent study of Celto-Roman temples [9], the altitudes a were simply replaced by the arc cosines of the squares of their cosines ($r = r_0 + \arccos(\cos^2 a)$) (Figure 9; note the completely different stellar arcs, which have shifted from the positions in the other

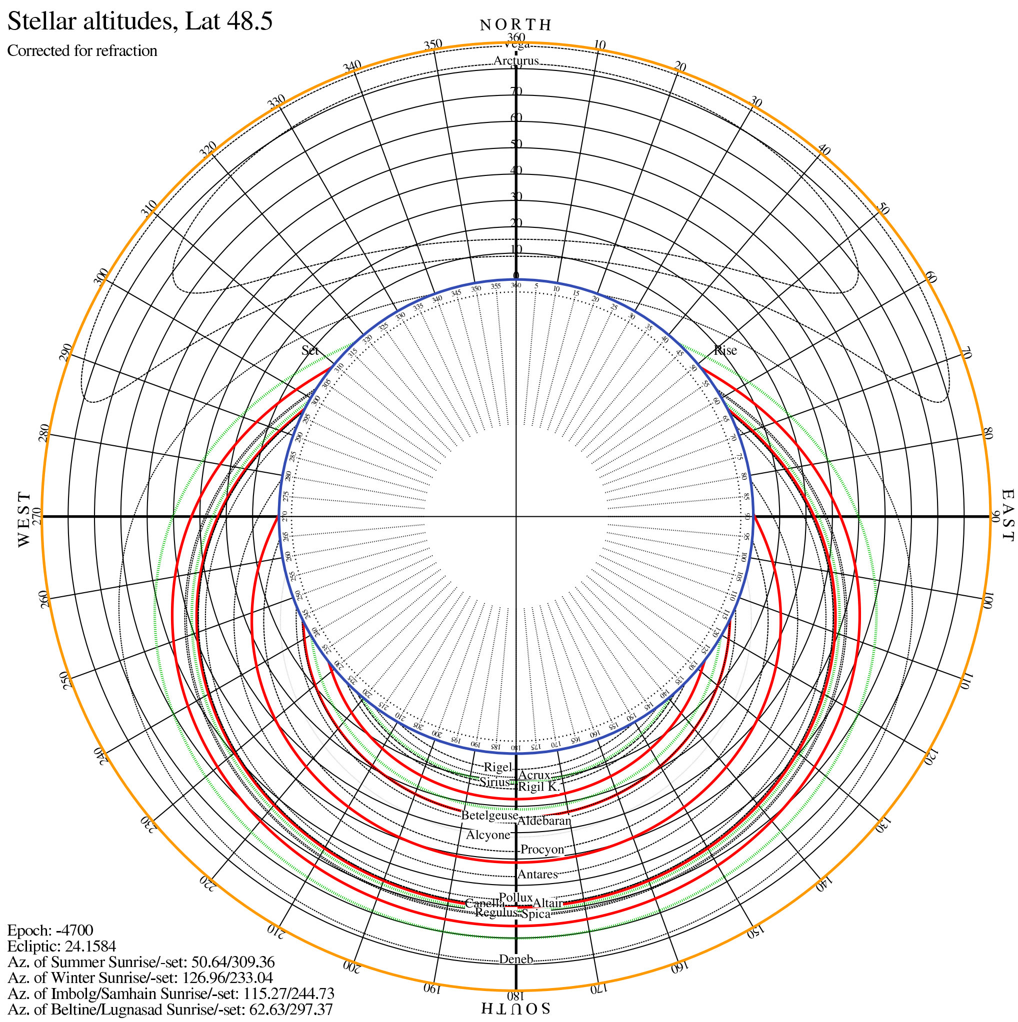

Figure 6: Flipped view of figure 4. The zenith (orange) is now mapped to the outermost circle, while the horizon (blue) encloses the inner area.

diagrams due to precession). Of course, other functions are usable and may be tried. On the other hand, stretching too much makes it harder to discern the diurnal arcs in the border of the diagram.

One further remark: Using simple lines for the Sun and the Moon will just show the trail of their respective centers. However, these bodies are approximately 1/2 degree in visual diameter, which can lead to a significant difference when investigating astronomical alignments. For a sunrise grazing upward along a distant hill, it can make a difference of several degrees in azimuth whether the first rays of sunlight (upper limb) should be pointed to, or the appearence of the complete solar disk. This difference also changes the calendar date found, because the Sun's rising azimuth moves northward ("left" as seen on the ground) between December and June solstices and southward in the other half of the year. So, diurnal arcs for these two bodies should be computed and plotted not for their centers, but for their upper and lower limbs, and the region between these lines may be filled. Now it is possible to discern on an enlargement of the horizon whether e.g. the Sun's first light (upper limb crossing horizon line) or its full visibility (lower limb crossing) may have been the target of an alignment, and the thick line will at last have a valuable meaning. Of course, the line thickness will vary if the altitudes are scaled in a nonlinear way.

3.4.2 More Fun with the Sun

From diurnal arcs of the Sun drawn for various dates of the year in this kind of map (Figure 10), dates for zenith passages of the sun can be estimated for sites between the tropics, which have been of interest e.g. to pre-Columbian peoples of Peru [3, p.181]. It may also be of interest to show *hour lines*, i.e. Sun positions at regular intervals from noon (which is defined by the Sun reaching its highest altitude for the respective day). In the Alpine regions, many villages have their chain of "hour mountains", and the Sun will be positioned roughly over these mountain tops at the respective hour, and they should stand out on the horizon plot.

Today we are familiar only with the concept of *equal hours*, dividing the day into 24 equal parts. However, in antiquity and medieval times, it seemed more natural to divide the day between sunrise and sunset into 12 hours, and to divide the night in a similar way. Because—except at the days of equinox—night and day are of different length, day and night hours were of unequal length, and the duration of these *unequal hours* varied during the course of the year. Early sundials show these hour lines, and the Spanish "siesta" still is the name of the sixth (unequal) hour of the day, i.e., noon. Old building structures involving small windows and wall ornaments sometimes are said to be aligned to show these hours by light spots shining onto them.

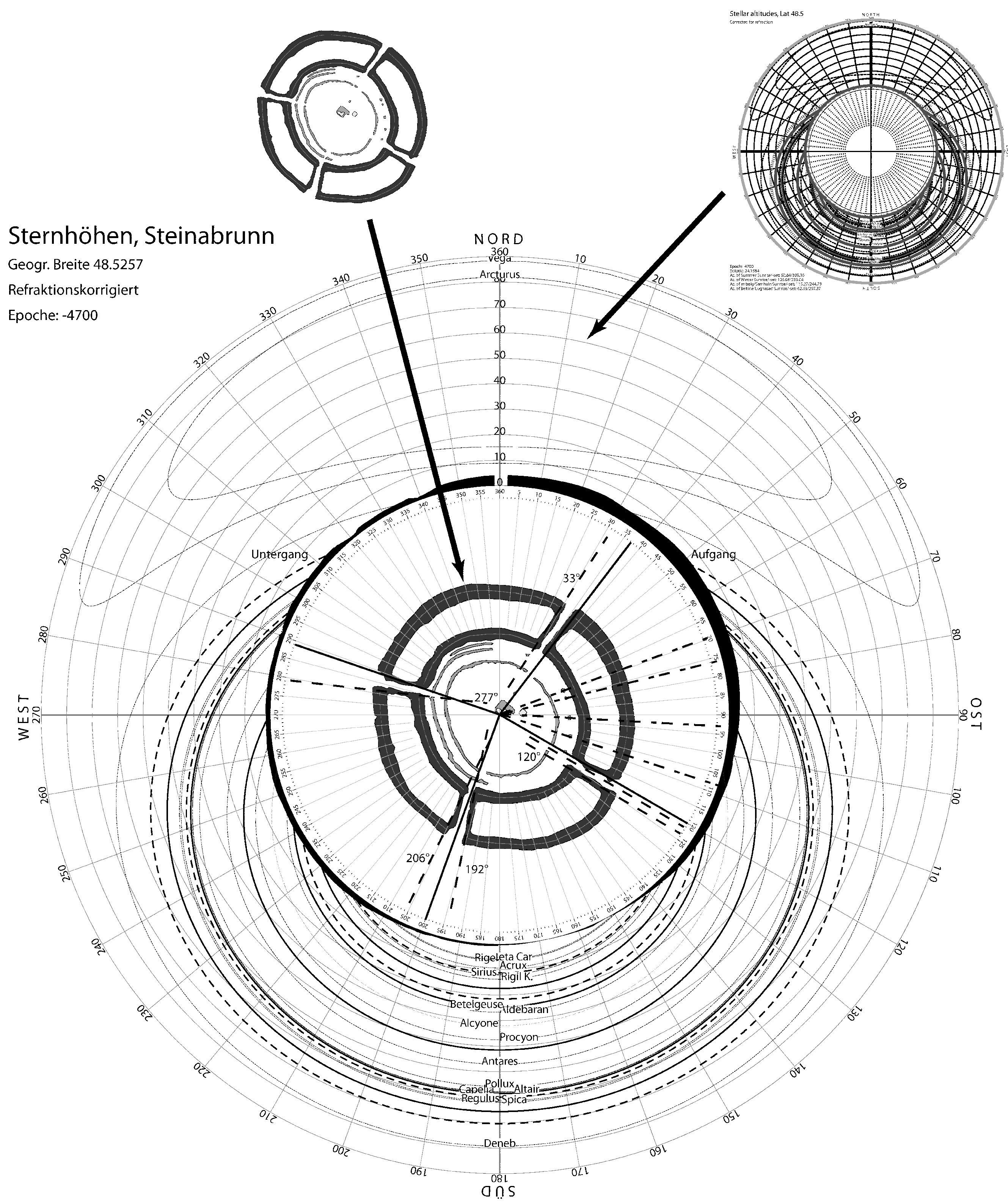

Figure 7: Combining the flipped star path map of figure 6 with data of the local horizon from GIS data (the thick irregular black zone along the horizon) and an archaeological map of the twofold *Kreisgrabenanlage* (KGA) of Steinabrunn [5] as example for an archaeological application. The radial lines indicate some of the plausible viewing directions along ditches, while the dashed lines indicate views through palisade gaps. Degree labels have been added where a line does not originate in the diagram's center.

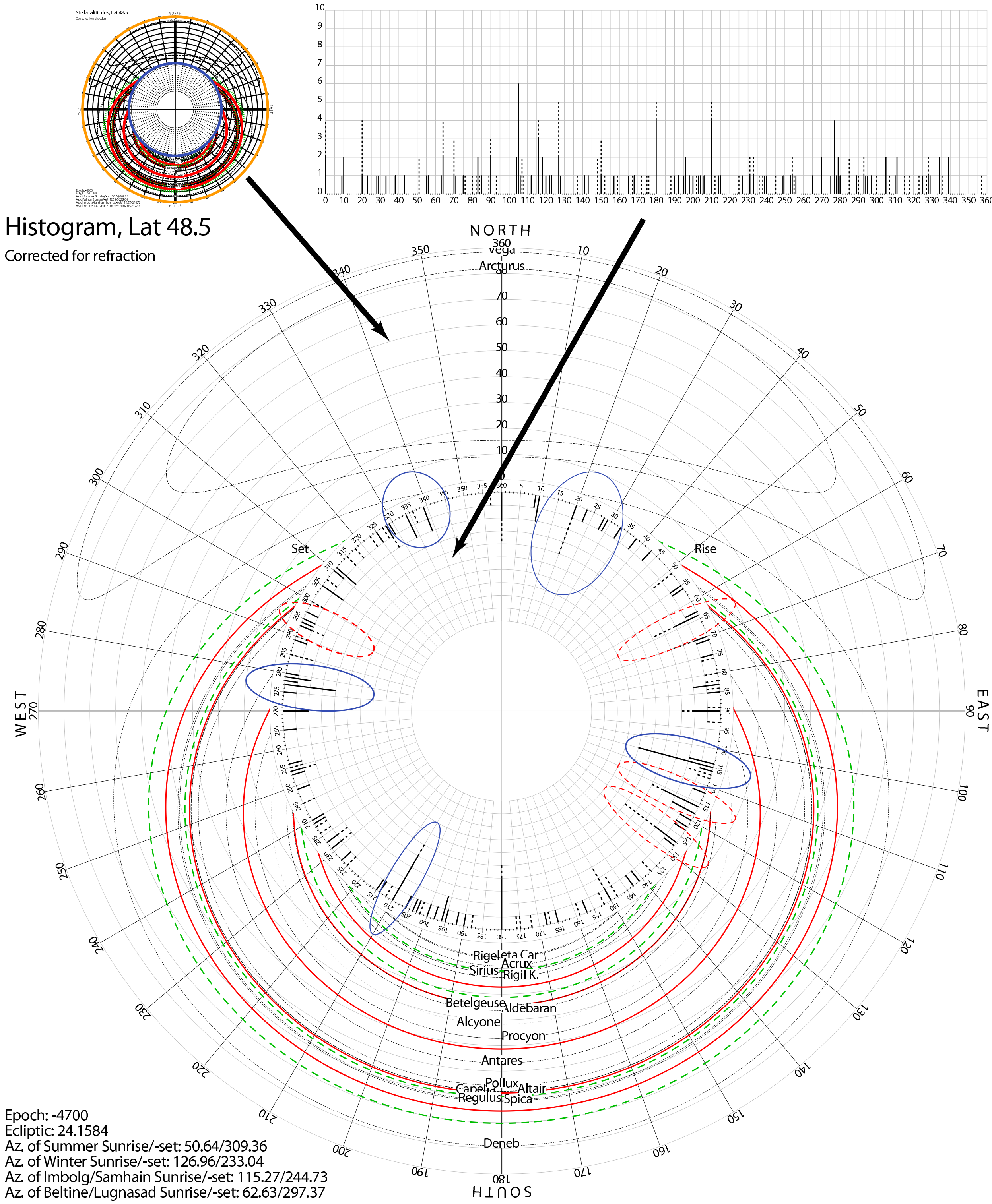

Figure 8: An ordinary rectangular histogram of all identified directions over azimuths of 28 *Kreisgrabenanlagen* (top right). The thick lines indicate the number of orientation lines pointing toward the respective azimuth. Full lines indicate directions of radial ditches or earth bridges, dashed lines indicate less conclusive gaps in the palisades. The histogram shows some peaks, but is hard to understand without the celestial context. Putting the histogram inside the mapping of figure 6, with lines pointing from the horizon circle towards the center, immediately shows the possible astronomical connection of these directions. North and south are clearly indicated in 2–4 respectively 4–5 KGAs, east and west only in 2–3 each. A few peaks indicate alignments to certain solar dates (marked with dashed ellipses): directions around 127° indicate Winter solstice sunrise, 115° and slightly southward (shifted by raised local horizons at several sites) apparently mark sunrise at start and end dates of a "Winter" season centered around solstice. A weak group near 64° and a larger group near 295° may indicate sunrise and sunset at beginning or end of a "Summer" season similarly centered around summer solstice, which is not strongly marked itself (at 50°). The strongest peaks however appear to be connected to stars (full ellipses). The strongest concentration lies in the range 104–108° with in total 9 strong and 3 more weak hits, which indicates the rising point of the Pleiades star cluster, marked here by the path of its brightest star, Alcyone. Almost on the opposite side, the setting direction of Antares is pointed to by 8 or even 9 strong hits in the range 275–280°. The calendarical interpretation of these peaks is described in section 4.

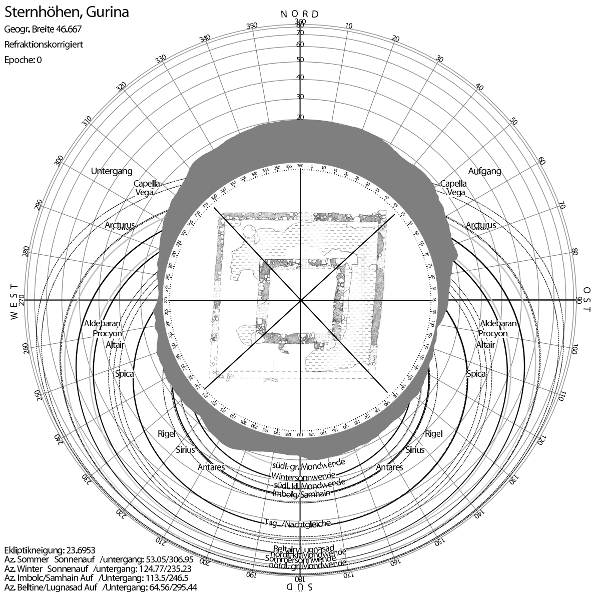

Figure 9: A nonlinear mapping of the altitudes improves readability along the horizon. Also, the arcs for the Sun and the Moon are computed for upper and lower limbs, then the region between is filled. This improves reliability over a simple thick line. The structure here lies in a valley running in a west-eastern direction with a high mountain ridge towards the north [9].

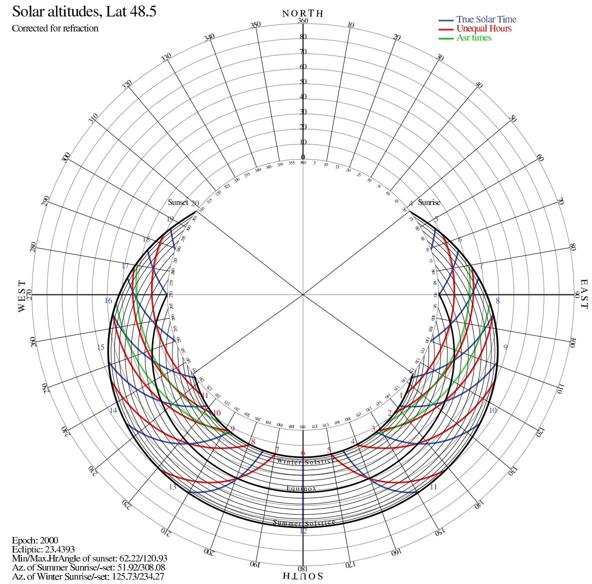

Figure 10: Flipped sky map showing diurnal arcs (daily paths) of the Sun, together with lines for equal hours (blue), unequal hours (red) and Islamic Asr times (green) as examples of interesting directions to look for in studies on solar orientation of buildings. The diurnal arcs now show the Sun's daily motion for every tenth day.

Of course, when looking for solar alignments in prehistoric archeological structures, we cannot assume the usage of a 12-partite day, still such lines can be used as guidelines to estimate the Sun's motion through the sky.

Another example for a possibility of solar alignment has been inspired by the Islamic rules to find the afternoon prayer times (asr). Measured with a simple pole, these times are defined by the pole's shadow length equaling the pole's noon shadow length extended by the pole's length (asr 1) or twice the pole's length (asr 2) [14]. Alignments towards the Sun's position at these times would have to include a very high local horizon or also artificial wall tops or windows, however, and cannot be seen in archeological structures if only foundation walls (or even less) remains.

4 Discoveries

A word of caution: Many azimuth directions one can find in an old building structure can provide some star that rises or sets there at some period in time. Therefore, investigations of singular buildings are always prone to the danger of overinterpretation. The histogram (Figure 8) shows many singular entries of gate directions, and many stars that seem to be pointed at. But not every door or wall was necessarily intended to be aligned towards some rising or setting point of a certain object. A current problem with the data is also the still incomplete set of horizon profiles, so that a complete evaluation cannot yet me made. However, it is possible to detect the largest accumulations of gate orientations, and the diagram can show us possible celestial objects that can explain the orientation. Here, an important point is that the visually most impressive accumulations are not centered around an object's diurnal path, but have their peaks slightly southwards of, and are *limited* in the north by the intersection of the diurnal path and the mathematical horizon. This southward shift is expected as effect of an elevated horizon.

Combined with either interactive desktop planetarium software or a self-made planisphere for the neolithic period, a skilled astronomer can then interpret a few of the detected accumulations of azimuth directions. In addition to the factual alignment visible from the diagram, we wanted to solve the question of *why* certain stars could have been so important that our far ancestors oriented their largest buildings towards them.

For the Sun, the most obvious direction accumulations are near azimuth 127° (Winter solstice) and south of 115° (Candlemas/All-Saints-Day), thus marking start, middle and end of a "Winter" season centered around the Winter solstice. On the northern side, an equally defined "Summer" appears to be marked mostly with begin/end dates, while the summer solstice seems to have been less important.

Still, it seems evident that not only solar directions have played a role in the orientations of *Kreisgrabenanlagen*. While the data currently do not offer a clear connection to lunar extremal risings or settings (green lines in figures 4 and 8, respectively), there are two striking peaks towards directions 104–108° and 275–280°. Indeed, around 4700 B.C., there have been two very conspicuous objects rising respectively setting at these directions: the Pleiades star cluster (rising) and the bright star Antares in Scorpius (setting). Moreover, the events of rising Pleiades and setting Antares took place *almost simultaneously*. Further investigation led to the conclusion that the Pleiades' heliacal rising (see section 2) took place just after spring equinox. It appears very likely that the neolithic farmers used this celestial event to start their agricultural year. Note that the Pleiades have been observed by many cultures worldwide in connection with the seasons [3], although a star cluster like the Pleiades, which consists of dim stars, cannot be observed below an extinction angle of about $a_E = 4°$, which is, however, a typical horizon elevation in Lower Austria.

Deneb, the Swan's tail star, joins the couple: just when Antares is setting and the Pleiades are rising, Deneb is highest in the sky, shining almost in the zenith. It is the northernmost bright star that sets below the northern horizon, and a wide group of doors and other sight lines appear to point towards it. Unfortunately, the intersections on the northern and southern horizon are very sensitive to elevated horizon lines, so the entries in the histogram, which cannot contain a horizon line, appear less concentrated. Figure 3 shows the scene where simultaneously Antares is setting near 275°, the Pleiades rise at 106° and Deneb culminates in the south in about 80° altitude (near center).

Also a frequently used southern gate direction (210°) required to look for a star setting there. Unfortunately, there are several stars sharing almost the same declination, but Rigel appears to be the brightest candidate. Further investigations in the field, taking measured horizon profiles, should clarify and narrow the error margins for this and all other directions.

4.1 User Reactions

Archeologists, who are largely unfamiliar with astronomical problems, but interested in possible astronomical influence in the culture of a studied epoch, were asked for their understanding of the diagram when applied to a different study [9]. Overall, the first reaction typically was that the diagram shows too many lines, and cannot stand without explanation. However, when properly described, they understood what can be seen, and accepted it as a tool for the solution of this specific type of investigation. The problem apparently lied not so much in reading the diagram itself, but in the elementary astronomical knowledge necessary to understand it.

5 Conclusion and Future Work

In this paper we have shown a simple, yet effective way to investigate buildings with known date of origin for astronomical orientations towards special rising and setting points of Sun, Moon and stars. The core item is a novel diagram combining a terrestrial map, e.g., of a building or other archaeological structure, and a folded-apart representation of the sky dome showing daily paths of celestial objects and the local horizon. We have shown how this diagram has been applied to a certain class of neolithic circular enclosures (*Kreisgrabenanlagen*), and have pointed out interesting discoveries made with a variant of the diagram which includes a histogram of alignments of a larger number of KGAs. These discoveries allowed us to produce renderings for selected points of view inside virtual reconstructions. These were used as foreground panoramas for commercial desktop planetarium software to create astronomical vistas and animations (e.g., Figure 1 from [15], where also the detailed astronomical results have been published).

Clearly, an optimal solution would be an interactive, navigable VR/AR environment with an astronomically correct and visually convincing high quality sky simulation, which would allow immediate investigation of virtual reconstructions of archaeological sites. Unfortunately, only partial solutions of such systems seem to exist. One such system has been used at UCLA's Cultural VR Lab [16], where research has been done on the solar orientation of the sacred Inca precinct of the Island of the Sun in Lake Titicaca, Bolivia [17]. One problem with current VR systems however is that 3D content development suitable for archeo-astronomical research is very time consuming and costly and needs lots of interdisciplinary expertise.

The concept of analyzing collected azimuth directions in a circular histogram could be extended to allow interactive work. Interactive brushing through a larger database of KGAs in a Geographical Information System (GIS) which includes their possible orientations and selecting, e.g., only archaeological sites in a specific region, could for example probably identify local traditions, although the total number of known KGAs in Europe (about 120 [18, p.4]) may be too small to deliver reliable results. If data from a long temporal series (several centuries) are investigated, the star paths will be seen shifting due to precession, still, for example an interactive investigation of the orientation of burial sites could probably find long-lasting traditions. In any case, dating the archaeological findings is necessary for any stellar position related investigation.

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