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Land- and Skyscapes of the *Camino de Santiago*: An Astronomy and World Heritage Sustainable Approach

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Citation: Urrutia-Aparicio, M.; Belmonte, J.A.; González-García, A.C. Land- and Skyscapes of the *Camino de Santiago*: An Astronomy and World Heritage Sustainable Approach. *Sustainability* **2022**, *14*, 3047. https://doi.org/10.3390/su14053047

Academic Editor: Giulio Magli

Received: 18 January 2022
Accepted: 2 March 2022
Published: 4 March 2022

Abstract: The Romanesque churches dotted along the Way of Saint James are magnificent examples of cultural heritage, and their analysis from the perspective of cultural astronomy may, in an unobtrusive manner, provide information of hitherto unexplored facets of these treasures. This study aims to examine the pilgrimage road as a communication channel and to seek possible regional variations in the Christian kingdoms of Leon, Castile, Navarre and Aragon. Seen as a whole, the Romanesque churches of our sample present two main orientation patterns: towards either the ecclesiastical and astronomical equinox or to certain Easter Sunday celestial phenomena. However, equinoctial orientations are present only in Leon and Navarre, while Easter appears with more or less significance in every kingdom. The *Camino de Santiago* constitutes a sacred landscape with a common heritage, with a certain degree of cultural diversity that depends on the territory. These subtle differences have surfaced only in light of archaeoastronomical investigations.

Keywords: cultural astronomy; church orientation; camino de santiago; romanesque architecture; easter; equinox; iberian peninsula

1. Introduction: The Road of the Stars

The reasons for the *Camino de Santiago*, aka the Way of Saint James, being inscribed on the World Heritage List in 1993 [1] are unquestionable: first, because of the wealth of cultural heritage arising from the multiple exchanges between the Iberian Peninsula and the rest of Europe, especially concerning Romanesque art and architecture (see Figure 1); second, the material record and its perdurability; and third, its display of the power and influence of faith during the Middle Ages.

(a) (b) (c) (d) (e)

Figure 1. Examples of Romanesque churches found along the French Way in the ancient Christian kingdoms: (**a**) San Pedro Fiz do Hospital in Galicia (Leon), (**b**) Santiago de Carrión de los Condes in Palencia (Castile), (**c**) Santo Sepulcro in Torres del Río (Navarre), (**d**) San Martín de Uncastillo in Zaragoza (Aragon) and (**e**) San Caprasio de Santa Cruz de la Serós in Huesca (Aragon). Note the differences in stone, structure, and decorative detail. © A.C. González García, M. Urrutia-Aparicio and P. Alonso-Arias.

Although the Way itself refers to an interconnected network rather than to a particular pilgrimage route, the French Way is the route with the greatest Jacobean tradition. The 'French' appellation is not vainly assigned given that people from the other side of the Pyrenees were the ones putting greater effort into the cultural diffusion of the Way and the construction of ecclesiastical buildings [2], mostly through the increasing impact of the Order of Cluny.

These pilgrimage roads can be understood as a way of sacralizing the medieval European landscape. They are crucial to interpreting and providing meaning to the sacred places which, for their part, shape and highlight the route [3]. From this point of view, the Way moulds a cultural landscape built over several sacred locations.

The growing cult of saintly relics helped to establish the physical location of such sacred sites [4] (which usually turned to be ecclesiastical buildings) where relics were put on display. The famous *Liber Sancti Iacobi* cites worthy relics found along the route belonging to Saint Dominic in Santo Domingo de la Calzada, Saints Facundus and Primitivus in Sahagún, Saint Isidore in Leon, and, presumably, Saint James—the Great (or the Elder), or even the head of the Less—in Santiago de Compostela [5].

The events that led to the discovery of the Apostle's relics, the *inventio*, developed during the first decades of the ninth century [6–8]. The well-known legend recounts that Paio the Hermit witnessed mysterious beams of light coming from the vestiges of an antique monument that would later be identified as the remains of the sepulchre of Saint

James the Apostle. According to local legend, this place, the *Campus Stellae* (Field of the Star), would become the name of the present-day city of Santiago de Compostela. This is not the only legend linking elements of the sky to the *Camino*. According to the fourth book of the *Codex Calixtinus*, the Apostle appeared in Charlemagne's dreams, urging the Emperor to follow a road of stars (probably the Milky Way) that led to Galicia, in order to fight the infidels [9]. This would have made Charlemagne the first pilgrim, and caused the Milky Way to become associated with the Way of Saint James. In fact, *Camino de Santiago* is the popular name given to the Milky Way in parts of Spain [10].

The remarkable relationship between the skyscape and the elements of the landscape is manifested in the alignments of various monuments [11], as proven by the initiative 'Risco Caído and the sacred mountains of Gran Canaria', which was inscribed in the UNESCO's list of World Heritage sites with the sky as a substantial attribute guaranteeing its outstanding universal value (OUV [12]). As shown below, the orientation of churches during their construction could have been linked to certain astronomical factors that are worth considering. Hence, in terms of the present paradigm, the study of the orientation of churches from the perspective of cultural astronomy could enhance the OUV of the *Camino de Santiago* in the context of the World Heritage Convention. In particular, the Jacobean route itself was declared a sacred landscape without reference to the astronomical paradigm; such astronomical input will certainly add new value to crucial aspects concerning the way in which the Romanesque churches are perceived by pilgrims.

Therefore, the present research aims to inquire into whether the orientation of the Romanesque churches in the *Camino* might provide information about possible cultural shifts in the different Christian kingdoms. Our hypothesis is that the orientation of churches could reflect the different religious, political, sociological, and economical influences at play during that time. As such, they may suggest certain dynamics related to the creation and evolution of the Way, and thus provide new data to interpret one of the most important pilgrimage routes worldwide to this day. in a unique way. As an example of cultural heritage preservation, enriching our understanding of these cultural sites can help in the development and application of sustainable touristic practices.

2. Elements in the Landscape: The Orientation of Christian Churches in the Iberian Peninsula

This research is in certain aspects a novelty in the scientific literature, the ~~a~~ logical continuation of a series of works developed to better understand the role played by the sky, and notably the sun, in the monumental tradition of the Iberian Peninsula. The topics have been diverse; beginning with megalithic phenomena [13] and followed by Iberian and Celtic studies [14,15], the Roman world [16,17], and early Christian shrines [18]. These works established a paradigm to which this article is indebted.

Indeed, the study of orientation patterns has proven to be a powerful tool, enabling us to delve into the relationship between astronomy and culture in the context of land- and skyscapes [19]. This approach is intrinsic to the discipline of archaeoastronomy, which is framed within cultural astronomy and studies it through material remains, especially architectural vestiges. The definitions and usage of these terms remain under debate; a broad explanation could be "any study of sky observational practices for cultural purposes (religion, metaphysics, divination, architecture, decoration, painting, city planning, time measurement, navigation, etc.), in any region of the planet" [20]. In addition, archaeoastronomy provides a non-invasive methodology that produces results easily accessible to the local communities, helping them understand, value and protect their heritage through the development of a sustainable method of research [21]. This could be the reason for archaeoastronomy's touching on as many different topics (such as ancient Egypt and the Near East, Prehistoric Europe, and pre-Columbian America) as it does [22,23]. Church orientation has of course been widely debated following the first analyses of Lockyer and Nissen [24,25].

In the Middle Ages, astronomical practices served Christian religious concerns, for instance, the determination of sacred feasts like Easter or the characteristics of sacred space, with the prevalent symbolism of orientating the churches eastward [26,27]. The importance of facing east during prayer had been noted from early sources such as *Didascalia* (II, 57, 5) at the end of the third century [28,29]. Whether this prescription was followed or not has been the subject of many debates in recent decades. González-García conducted a critical review and collected several works prior to 2011 from European and North African churches with the aim of discussing the general picture [30], and mentions a general eastward orientation for all the churches, regardless of country and epoch. However, regional variations appear, perhaps brought about by different methodological approaches or interpretations of the prescription. Ten years after the publication of this work, church orientation continues to attract many researchers from different regions [31–36].

Pre-Romanesque churches in the Iberian Peninsula have been analysed by González-García and Belmonte, who identified both general tendencies and the specificity of each style or period of construction [18]. A very interesting case relates to Asturian churches built during the 9th century, which are aligned north of east, apparently to avoid orientations similar to those of the mosques of Al Andalus [37].

These churches were studied by Pérez Valcárcel, who has continued to be very active after he published the first Spanish article on this subject in 1998 [38]. He proposed the date of the construction of the church as an explanation for the orientation patterns, and mentioned Easter as another possible target, while discarding orientations towards the sunrise on the patron saint's day. His research includes the orientation patterns of pre-Romanesque and Romanesque churches [39,40], churches inside castles [41], and even some atypical cases of orientation found in different surveys [42,43]. Despite the vast number of measured monuments, his earlier work lacked data on the horizon altitude, which should be mandatory in such discussion.

In recent years, various authors have worked on the Romanesque churches in the area of Val d'Aran in the Pyrenees [44,45]. Their innovative approach has provided proof of orientation techniques without direct observation of the sun on the horizon [46]. These methods, which can guarantee precise equinoctial orientations, were known by the builders of that period and could have been useful in places with high horizons. Apart from this, they discussed the resemblance to churches in the Bohí Valley, previously studied by González-García and Belmonte [21].

These researchers, along with Urrutia-Aparicio, recently identified Easter Sunday and the ecclesiastical equinox as the two main landmarks for the general orientation patterns of Romanesque churches in the western kingdoms of the Iberian Peninsula, which are traversed by the Way of Saint James [47]. Additionally, in a subsequent paper, they conducted a more detailed analysis of these regions and used contrasting samples of churches located at a distance from the Way, thus presenting proof of regional variations within the ancient Christian kingdoms of Castile and Leon [48].

Churches erected after the twelfth century in the southern regions of the Iberian Peninsula have been studied by Abril, who has proposed observation of the sun above the horizon as a method for the alignment of a sample of churches devoted to the Virgin of the Assumption that are apparently aligned to sunrise on the Feast of the Assumption on 25 March [49]. In a recent study, the same author analysed the orientation patterns of a number of Gothic–Mudejar churches built after the Reconquest of Muslim Andalusia by the Christian kingdoms [50]. Interestingly, the comparison of these temples to a group of mosques of the same region suggests that the orientations of the churches were orthogonal to that of the qibla and match the ancient canonical equinox of 25 March, which is the date of the Feast of the Annunciation.

Finally, it is worth mentioning the effort made to study churches in the Canary Islands; built throughout the fifteenth century and beyond after the conquest of the archipelago by the Castilian Crown, their orientation patterns seem to be subordinated to other considerations. For example, the churches in La Gomera are conditioned by the orography of the island [51]; in contrast, the strong winds of Lanzarote are the reason for the more northerly orientations of churches there [52]. An investigation into the churches of Fuerteventura is currently under way. This island, despite being similar to Lanzarote in terms of the presence of north-eastern strong winds and lack of high mountains, differs in its orientation patterns, and alternative explanations need to be sought [53].

In sum, churches in Spain display a wide variety of orientation patterns in terms of both targets and everyday needs as well as the methods followed by their builders to obtain the desired orientation. Although most of their orientations are interpreted as eastward, there are clear differences depending on the region or the period of construction. An in-depth and careful analysis of a coherent, comprehensive, and related sample such as the Romanesque churches along the Way of Saint James could give information about these distinctive details, as proven by the above-mentioned studies.

3. Methods

All the churches analysed here are shown in Figure 2, which covers the ancient kingdoms of Leon, Castile, Navarre and Aragon. The regional division of the Christian kingdoms is based on the map of AD 1147 provided by the Spanish National Atlas of the National Geographic Institute [54]. However, the autonomous regions of present-day Spain are slightly different. This is the case, for example, in La Rioja, which was a constant cause of dispute between Castile and Navarre. Indeed, this territory was invaded by Alphonsus VI in 1074 and incorporated to the kingdom of Castile two years later. After that, Sancho VI of Navarre reconquered parts of La Rioja, and finally in 1177 almost every part of the region was ceded to Castile. This is the main reason why we have included La Rioja as a part of Castile.

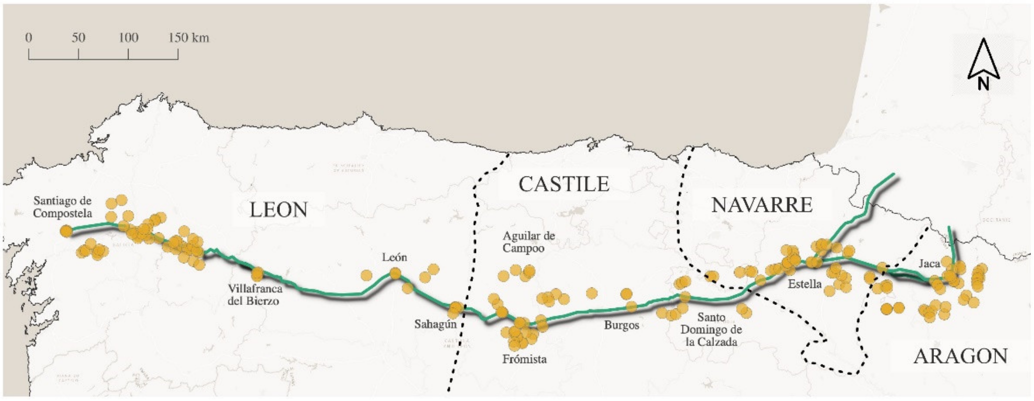

Figure 2. Map of the survey undertaken by the authors. The present-day French Way is represented by a solid line, with the two paths that enter from France into Roncesvalles in Navarre and Somport in Aragon. The ancient kingdoms as of c. 1150 are marked by dashed lines to indicate their approximate locations. Finally, the locations of the Romanesque churches near the Way are indicated by circles. Note the emptiness between Villafranca del Bierzo and the city of León and the accumulation of churches in Aragon, around the same longitude. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

For this analysis, and given their proximity to the Aragonese stretch of the Jacobean route, we have added to the sample data for Serrablo churches [18], built during the 10th and 11th centuries. Whether this unique group belongs to an early Romanesque style with a Lombardic influence or to the Mozarabic style has been a matter of debate that is beyond the scope of the present paper [55].

The selected orientation axis, as shown in Figure 3, is the line that crosses the church from the narthex to the apse, in the direction of the latter. This measurement provides the azimuth value that is key to the analysis. Churches usually underwent several reforms over the centuries, and it is important always to follow the same criteria: they must maintain any of the "measurable" Romanesque features, such as the apse, a façade or a porch that we know has not been subsequently shifted or moved to a new location. Restored buildings that respect the original plan were included with prior verification. The Santa María la Real Foundation published a highly detailed online encyclopaedia dedicated to the Romanesque buildings of Spain [56], and information provided by councils, compilation books and websites was helpful as well [57,58].

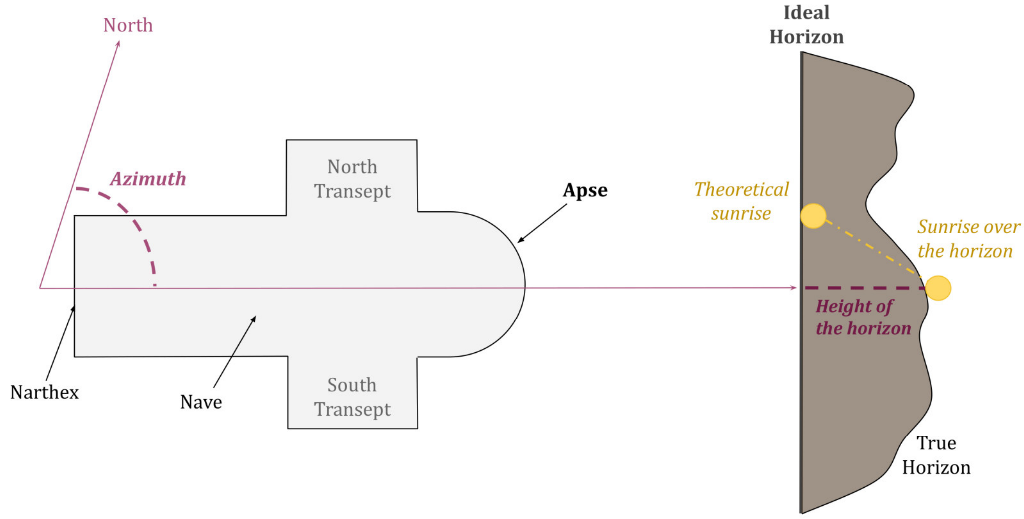

Figure 3. Layout of a typical church, with its orientation axis marked by an arrow pointing towards an irregular horizon. Its angular height in that direction is key to obtaining the path of the sun, starting from the ideal flat horizon to the actual sunrise. These two measurements, the azimuth and the height of the horizon, can then be used to calculate the declination. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

Once the orientation was determined, we obtained the angular height of the horizon in that direction. This magnitude is crucial for knowing whether the builders were using direct observation of the Sun over the horizon to fix a particular orientation. The horizon was occasionally blocked by new buildings or vegetation. In these cases, we used the digital elevation model available in HeyWhatsThat [59] or Google Earth [60]. Their reliability with respect to in situ measurements is reasonable, with an estimated error of ± ½° [61].

These measurements were obtained with a professional compass and clinometer tandem, which had errors of ± ¼° and ± ½°, respectively. Afterwards, the azimuth was corrected for magnetic variation using either direct solar observations at given times, or the IGN or the NOAA calculators [62,63]; significant alterations were not expected in these locations. Refraction effects must be considered for the angular heights, especially for the lower values [64]. The associated errors were calculated using the standard deviation of the several azimuth measurements for each church and then adding the instrumental error by summing in quadrature.

Finally, we calculated the declination value for each of the azimuth and horizon altitude values [65,66]. This astronomical magnitude offers the advantages of comparing the orientation of structures located at very different latitudes and associating certain orientation patterns with bodies or astronomical events at any given epoch. The corresponding declination errors were then calculated by propagation for a mean value of 0.8°.

In total, we measured the orientation of nearly three hundred churches across the Way of Saint James. Appendix A includes new unpublished data belonging to the eastern area of the French Way, completing previous campaigns in the western territories [47,48]. The data include the geographical location of each church, its consecration, and the modern Spanish autonomous region it belongs to.

The analysis was performed through three types of plots: orientation diagrams, curvigrams, and declination frequency maps. The first two have been widely used in recent decades in archaeoastronomy.

The curvigram is a sum of several kernel density estimates (KDEs) that provides the probability of finding a certain orientation for a given sample. To build it, we followed the methodology already explained in previous studies [67,68]; that is, applying an Epanechnikov kernel function and a bandwidth of twice the error.

In the case of the declination magnitude, the resulting curvigram was then compared with other likely distributions in order to test whether the maxima were statistically significant [17,47,69]. One distribution was obtained from a sample of azimuths homogeneously distributed between 0° and 359° for a flat horizon and a latitude of 42½°, which is the mean latitude of the churches located along the Way. The other represented the declination values of the Sun throughout a solar year and was computed using the equation of time [70]. Normalization was carried out by subtracting one of these distributions from the observed one and dividing the result by the mean of the standard deviation of several random samples taken from the homogeneous or solar distributions. These samples were always the same size as the real measured sample. In this way, we determined the 3σ level above which the maxima may be considered statistically significant.

Finally, the frequency map was the result of a combination of two curvigrams, one for the declination and the other for a geographical magnitude (in this case the longitude) plotted together. With this measure we were able to estimate the probability of obtaining a specific declination value at a specific location of the Way. Note that this is similar to adding another dimension to the usual declination curvigram. The relative frequency of certain coupled values of longitude and declination were represented by a colour scale in which red indicates those of greater significance. Although the whole sample may be analysed by separated subsamples from every kingdom, this method allows an overall unbiased picture of the orientations of the Romanesque churches throughout the northern Iberian Peninsula.

4. Results

General orientation patterns can be detected by simply plotting all the azimuth values together (Figure 4). Of all the churches near the Way, only nine (4%) are strictly beyond solar range, that is, with azimuth values lower than the summer solstice and higher than the winter solstice at that latitude, without taking into account the associated error. This means that nearly every church faces the sunrise on some day of the year.

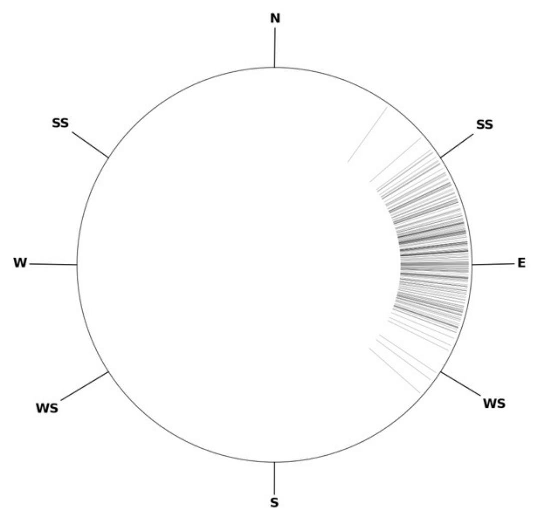

Figure 4. The orientation values of all measured churches near the French Way. The orientation of each church is presented as a solid stroke inside the circle. Summer and winter solstices (SS and WS, respectively) are marked by solid lines outside. Almost all of the churches seem to fall within the

solar range, with a preference for the eastern part of the horizon. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

This eastward pattern becomes even clearer in the declination curvigram (Figure 5), which shows a more precise orientation tendency than in the azimuth diagram. Rather than having a single peak centred on astronomical or true east, marked at δ = 0°, we find two maxima at positive declinations to the north of east. The most significant is located at 9½° and the second at 2½°, both with minor dispersion. These general orientation patterns could point to Easter Sunday dates and the ecclesiastical equinox of 21 March in the Julian calendar, respectively.

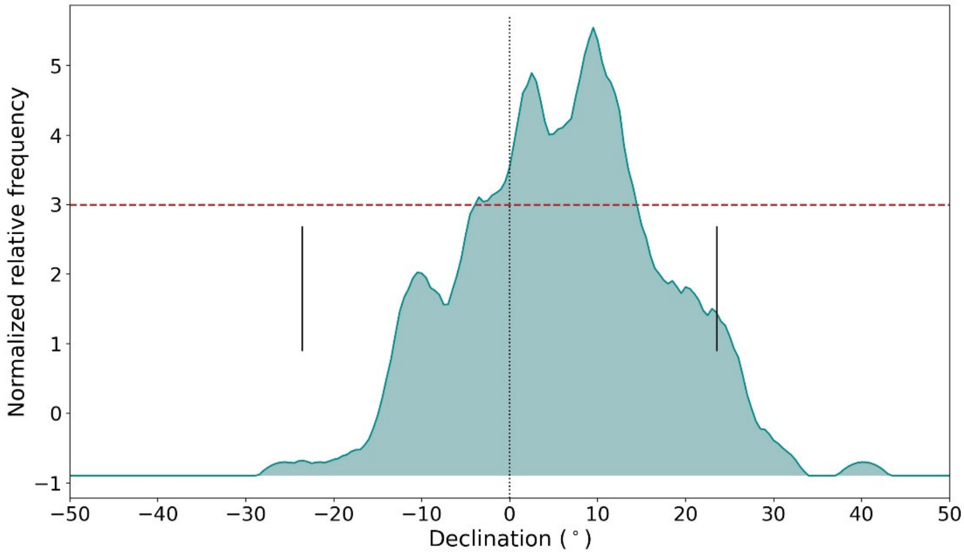

Figure 5. Declination curvigram of all measured churches near the French Way. Winter and summer solstices are marked by solid vertical lines. The astronomical equinox is represented with a dotted vertical line at δ = 0°. The significant peaks are those with maxima above the red dashed line, one at 9½° and a second one at 2½°. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

As indicated above, the French Way was divided among the four different kingdoms at the time, each with its own particularities; a more detailed study can provide an idea of their interactions or potential influences.

The azimuth curvigram of each territory is shown in Figure 6. The first thing that becomes apparent is that every kingdom seems to obey its own orientation pattern within the eastern horizon scheme. Orientations deviating north of east, i.e., azimuth values lower than 90°, can be found in all of them, whereas orientations towards south of east are more frequently found in Leon and Aragon. Finally, a clearly equinoctial concentration appears for the churches in Navarre and possibly in Leon as well, and it is almost completely absent in Castile and Aragon.

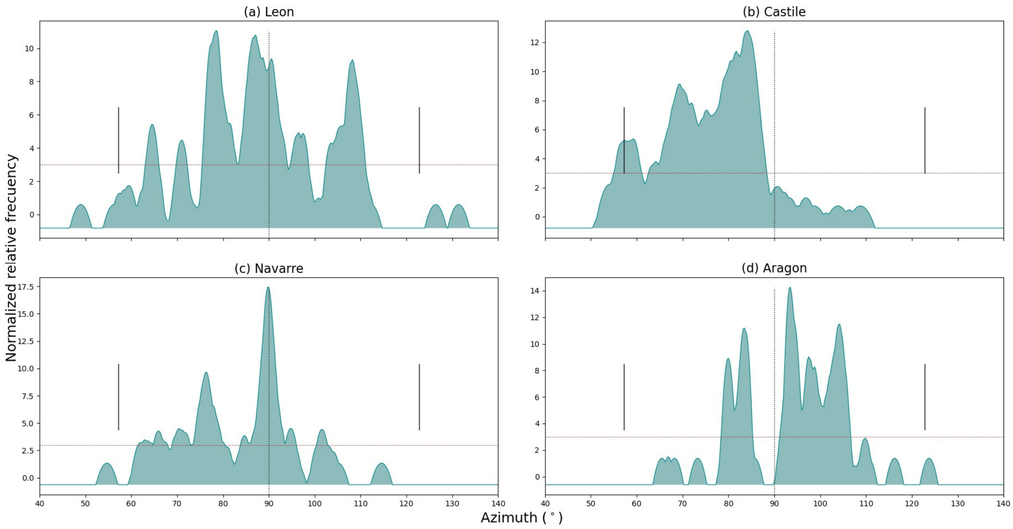

Figure 6. Azimuth curvigrams of the four kingdoms: (**a**) Leon, (**b**) Castile (including present-day La Rioja), (**c**) Navarre, and (**d**) Aragon (including Serrablo churches). © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

A comparison of declination curvigrams for the ancient Christian kingdoms is presented in Figure 7, and the respective maxima per kingdom are shown in Table 1. The concentration peaks are more complex than was expected, and merit further detailed analysis.

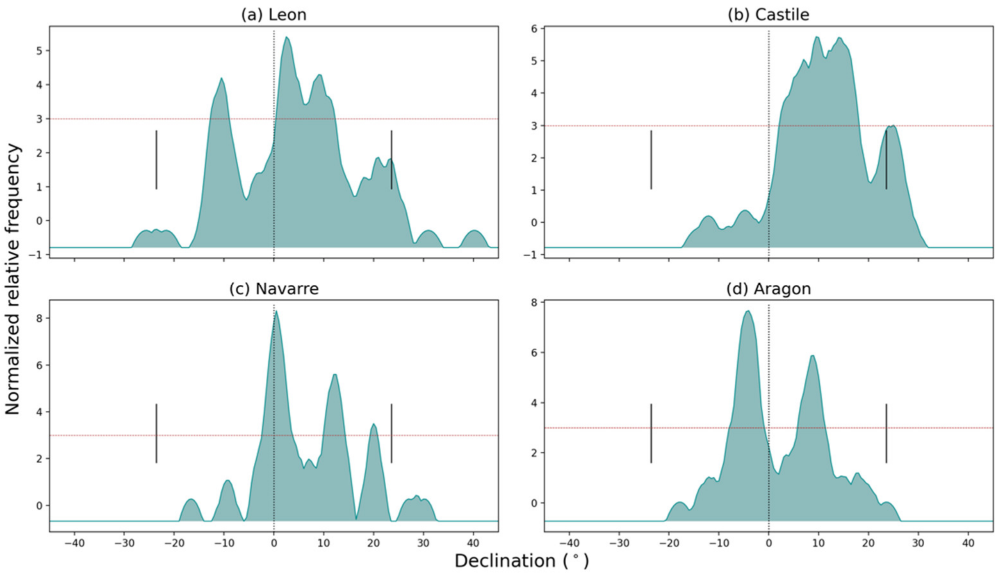

Figure 7. Declination curvigrams of the four kingdoms: (**a**) Leon, (**b**) Castile, (**c**) Navarre, and (**d**) Aragon. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

Table 1. Main declination peaks for each medieval kingdom: Leon, Castile, Navarre, and Aragon. Castile includes new data from La Rioja, and Aragon incorporates Serrablo churches. The associated uncertainties were obtained by the median of the errors per kingdom. Translated into Julian dates, they normally indicate two or exceptionally three days before and after the given day.

Kingdom	Declination (°)	Julian Date for 1150
Leon	2.6 ± 0.7	20 March/12 September
	9.0 ± 0.7	5 April/26 August
	–10.4 ± 0.7	13 February/16 October
Castile	9.6 ± 0.9	7 April/24 August
	14.0 ± 0.9	20 April/12 August
	7.1 ± 0.9	31 March/31 August
Navarre	0.5 ± 0.6	14 March/17 September
	12.3 ± 0.6	14 April/17 August
	20.0 ± 0.6	11 May/21 July
Aragon	–4.1 ± 0.7	2 March/29 September
	8.8 ± 0.7	5 April/27 August

5. Discussion

The northward deviation present in the complete sample of orientations (see Figure 5) has been explained previously as a result of the wandering Julian calendar [47]. If a particular date was systematically used to fix the orientation of a church, then after a certain period the sun would not rise at the same precise spot that day owing to the difference between the Julian mean year (365.25 days) and the tropical solar year. The year in the Julian calendar is longer than the tropical year, and after 128 years the calendar gains one day. For instance, for AD 21 March 325, when the canonical equinox agreed with the true equinox the declination of the sun was at 0°; however, on the same day for AD 1150, the declination had changed to c. 3° and the astronomical equinox occurred around eight days earlier. It is interesting to note the choice of 21 March rather than 25 March, which had apparently been chosen for the pre-Romanesque churches on the Iberian Peninsula and coincides with the Feast of the Annunciation [18].

The peak at c. 9°, though, cannot be considered an equinoctial one. Instead, in a recent analysis, Urrutia-Aparicio et al. argued the importance of Easter Sunday when orienting churches, particularly in the Way of Saint James [47]. The Easter dates from 22 March to 25 April would correspond to a range of declinations between 3° and 16°, with three main peaks at c. 7°, 9° and 13°. Actually, our maximum would match 5 April, one of the most-repeated dates for Easter Sunday on the period from AD 1000 to 1300.

The epoch in which Romanesque architecture spread across the Iberian Peninsula was a very turbulent one. The Christian kingdoms were fighting constantly, marching both against each other to unify or separate their inner territories and against the Muslim domain to the south. As borders were frequently changing, it is difficult to separate the churches into different kingdoms. Moreover, many of the churches lack documentation establishing a precise construction date, which could sometimes be determinant. In spite of this, a separate analysis of each Kingdom may provide an interesting perspective.

5.1. Leon

The most significant peaks in Leon, at c. 3° and c. 9°, are probably related to the ecclesiastical equinox of 21 March and Easter, as explained above. The exception is at declination c. −10°, which belongs to a group of churches from Santiago de Compostela and Sahagún. The first seems to follow the planimetry of the city, while the second apparently follows the orientation of Cluny Abbey [48].

5.2. Castile

The wide range of peaks in Castile could be associated with Easter, as stated in aforementioned studies [47,48]. In comparison to these, the addition of La Rioja highlights declinations related to the most repeated Easter Sunday dates. Churches from the lower part of La Rioja were studied previously by Martín Escorza, who noted a continuity in orientation patterns until the 20th century [71]. Most are apparently orientated towards the north of east; unfortunately, the author does not provide the height of the horizon, and the sample of churches from the twelfth century is small.

On the other hand, the accumulation around the summer solstice is present in both the azimuth and declination histograms and corresponds to eight churches, almost all of them with Marian invocation. The exception is one church consecrated to Saint Lucy in Collazos de Boedo, which might be pointing towards the sunset over the horizon on 13 December, the feast day of this saint. Another group of three churches with rectangular apses are less than ten kilometres apart from each other and belong to the institution of *Las nueve Villas de Campos* in Palencia [72]. One of them was associated with the Order of Saint John of Jerusalem; apart from these particularities, we did not find any strong evidence explaining a solstice alignment.

5.3. Navarre

The main declination peak in Navarre is quite remarkable, as it is close to the astronomical equinox at 0°. Contrary to its neighbours, it might be argued that this is a case where the builders decided not to follow the sunrise on a fixed date to set the orientation of the church. The azimuth curvigram in Figure 6c shows the peak centred on due east, which means the height of the horizon did not play a decisive role. Thus, the builders may have used an instrument such as a gnomon to establish the desired direction.

Although orientation towards the astronomical equinox is unusual, one example can be found in the nearby region of Val d'Aran. Various researchers have suggested methods based on solar observation and the use of an instrumental set-up to obtain a precise equinoctial direction [46]. According to them, these techniques were already known during the ninth century in southern France and in Ripoll, an influential Spanish village located near the Pyrenees and the French border.

The secondary peak is at a declination of c. 12°, which translates to sunrise on 14 April or 17 August (Julian dates). The latter could be associated (within the limits of declination uncertainties) with the Assumption of Mary celebrated on 15 August. When searching for the consecration of churches with this declination the possibility of relating their orientation to the sunrise on the day of this feast diminishes abruptly. Nonetheless, the date of 14 April, along with 5 and 6 April, is one of the most repeated Easter Sunday dates in the period under consideration. Further evidence is gained from the churches of Saint Mary 'Jus del Castillo' in Estella and Saint Martin of Unx. Both were built in years when Easter Sunday fell on 15 April, the first in 1145 and the other apparently in 1156 [73,74]. Although it is difficult to prove this hypothesis for each individual case, as not every church preserves the documentation indicating the date of its layout and reform phases, it is remarkable that in these two cases we find historical support for this working hypothesis.

Finally, a third peak is found at a declination of c. 20°, which is close to 25 July and within the margin of error. This is the only case in the present sample that could reveal an orientation preference towards sunrise on a feast related to Saint James. According to a previous work on pre-Romanesque churches, Mozarabic churches built in the north of the Iberian Peninsula present a secondary peak at c. 19° (25 July for AD 1050) [18], which could indicate a continuity in time.

5.4. Aragon

The largest maximum in Aragon is at a negative declination, c.−4°, which corresponds approximately to 2 March and 29 September. There are no important feasts around these dates that could match the invocation of the churches involved. Moreover, this group with negative declinations does not appear to have anything special or distinctive in common. The shape of the maximum seems to preclude the use of a gnomon, unlike the earlier case of Navarre. We then wondered what the declination would be if the churches orientated towards the western horizon. To examine this possibility, we added 180° to the measured azimuth and obtained the height of the horizon in that direction using HeyWhatsThat [59].

Figure 8 shows the new declination curvigram, which maintains the previous churches with positive declinations eastwards and changes the negative ones towards the west. In this way, the figure displays a single peak at c. 9° that matches the initial one in Figure 7d, with an admittedly higher statistical significance. Easter Sunday seems to be a possible and solid orientation pattern for these churches, which would again be in agreement with the results obtained for the kingdoms of Leon and Castile.

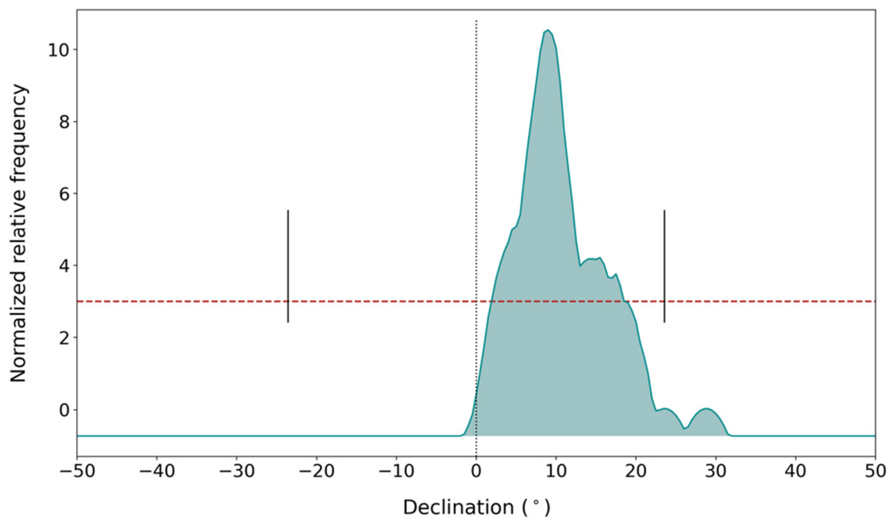

Figure 8. Declination curvigram of the churches of Aragon, this time considering westward orientations for the group with negative declination values (see Figure 6d). The result is a major peak at c. 9°, possibly related to Easter. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

The reason these churches should follow such a western orientation pattern remains unknown, although this may not be an isolated case. Romanesque churches of the mountainous region of Palencia present significant double declination and azimuth peaks, one of which translates into negative declinations [48]. However, none of the proposed hypotheses was able successfully to explain the whole sample.

5.5. *The Way*

Figure 9 represents the probability of finding a certain declination value depending on the geographical longitude. Therefore, we can easily compare the orientation of the churches by considering the physical continuity of the pilgrimage road along the north of the Iberian Peninsula. This is because the latitude values are similar along the Way, with the exception of the area around Jaca (Aragon), where the pilgrimage road enters north–south from France; thus, the churches are concentrated in similar longitude values.

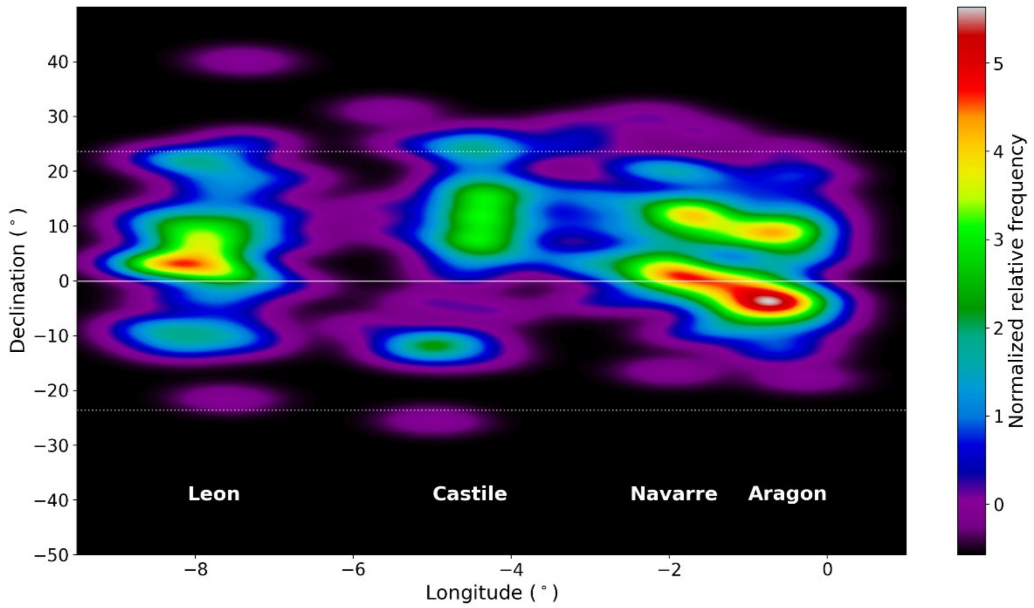

Figure 9. Declination frequency map of Way churches. Their locations are expressed in terms of geographical longitude, as the latitude is roughly the same all along the Way. Significant peaks are coloured bright green, yellow, and red, from lower to higher. White dashed lines represent the summer and winter solstices and the solid line represents the equinoxes. Most of the churches fall within the solar arc, with ~~minor~~ regional variations. The kingdoms of Leon and Navarre present equinoctial orientations, whereas Easter seems to be a secondary option. Churches in Castile seem to avoid the equinox and have a clear preference for Easter dates. The double peak in Aragon with negative declinations could be related to Easter, considering orientations towards sunset; see text for further details. The relatively isolated spots with negative declinations at longitude values −5 and —8 correspond to the churches in Sahagún and Santiago in the kingdom of Leon. © M. Urrutia-Aparicio, J.A. Belmonte and A.C. González-García.

This method excludes any cultural, political, or religious boundaries, and thus provides a non-filtered view of the orientation patterns. In the previous analysis by kingdoms, the year AD 1150 was selected as a mean value of the period when Romanesque architecture was spread across the Peninsula, and the whole sample of churches divided into groups depending on the kingdom to which they belonged in that year. Although this is a reasonable approximation, the reality is far more complex. As previously mentioned, physical boundaries were constantly changing during this period owing to conflicts between kingdoms, and the areas covered might have been different from those of the dioceses. Thus, cultural exchange could have happened through proximity or through political or religious influences.

Equinoctial orientations, whether astronomical or fixed to a certain date, are present and dominant in Leon and Navarre. More specifically, it is the region of Galicia in Leon where these orientations are found, possibly related to pre-Romanesque customs [75]. Rather strangely, the kingdom between them, Castile, does not have many churches with equinoctial orientations.

Easter appears as the second option in Leon and Navarre, and seems the preferred option in Castile and Aragon. Negative declinations in the latter could be transformed into Easter declination by considering the orientation towards sunset instead of sunrise, as already discussed.

Finally, we find that the main peaks at negative declinations corresponding to Santiago de Compostela and Sahagún from Figure 7a are, as expected, less significant when considering their longitude values, although they are clearly distinguishable. In contrast, the peaks at summer solstice in Castile and, in a way, Leon, become slightly more significant.

Several factors could have been responsible for such a difference between the kingdoms. One could be the gradual replacement of the traditional Visigothic rite by the Roman rite as part of ecclesiastical reforms initiated in the time of Pope Leo IX (AD 1049–1054) and promoted by Pope Gregory VII (AD 1073–1085). The change, however, was not carried out instantaneously in all regions.

According to Sánchez Domingo [76], the territory of Galicia in Leon had adopted the Roman liturgy in the 6th century under Suebian rule; however, this was later prohibited in order to unify the liturgy of all the churches in the Visigothic realm. The Pyrenean areas implanted the new rite in the 9th century possibly due to Carolingian influence. The same author argues that Aragon and Navarre abandoned the traditional rite before Castile and Leon under French influence and with the encouragement of the Order of Cluny, who contributed notably to ecclesiastical reform and promoted the Jacobean pilgrimage as well as the expansion of Romanesque architecture.

Whatever the case may be, any such analysis is beyond the scope of the present paper, which is focused on demonstrating how astronomical heritage as related to Christian religion is reflected in the orientation of churches and associated with various cultural and historical aspects of the landscape of the Way of Saint James.

6. Conclusions

The Romanesque churches along the *Camino de Santiago* follow a general pattern of orientation towards north of due east. The equinox and Easter Sunday seem to be the principal alignments pursued, although regional nuances appear.

In Leon, the most significant peak is probably related to sunrise at the ecclesiastical equinox, similar to the Pre-Romanesque churches [75], and Easter Sunday cannot be neglected. On the contrary, the churches from the neighbouring kingdom of Castile, including those from La Rioja, mainly present Easter orientations, and none present equinoctial orientations.

Moving towards the eastern kingdoms of the Jacobean route, Navarre shows a predominant peak at the astronomical equinox. Interestingly, this orientation was not obtained by direct observation of the sun over the horizon, and possibly used an indirect method such as a *gnomon*. Easter again appears as a secondary target.

Finally, the churches of Aragon comprise an unusual group, possibly with Easter alignments towards sunrise and sunset on the chosen day. A similar case can be found in the mountainous region of Palencia in Castile; unfortunately, it was not possible to find a satisfactory explanation for any of these cases.

Orientations towards Easter Sunday ostensibly constitute a common heritage of the Romanesque churches along the French Way, although this is not predominant in all the kingdoms crossed by the route, possibly owing to the complicated historical circumstances of the time.

The Way constitutes a unique and sacred shared route with a common heritage and style, with different cultural assets and traditions depending on the territories and political entities involved. In fact, through this study it has been possible to show the potential of the perspective of cultural astronomy in the enhancement of heritage in an impressive cultural landscape such as the *Camino de Santiago*. As already argued, the Jacobean route has developed today into a world reference in the context of heritage preservation and the development and application of novel sustainable touristic practices. Our work adds new value to these aspects, including the skyscape as a new facet reinforcing the Outstanding Universal Value of the property as a World Heritage Site, and hence increasing the well-known interest of the public in the sky above us.

Every year at the spring equinox dozens of people gather in San Juan de Ortega (Burgos), one of the Romanesque churches along the *Camino*, to observe the illumination phenomenon related to the Annunciation. To date, this has been an exceptional practice among the other churches of the Way. Our work certainly extends the potential interest of such astronomical relationships to the churches of the Way more generally, bringing new value to the cultural and touristic offerings of this pilgrimage route. In this sense, our team is currently analyzing potential illumination phenomena at several churches along the Way, a topic that has already attracted several authors [77,78].

In future works, the patterns found in the present paper ought to be compared to a sample of southern French Romanesque churches in order to study possible similar influences in neighbouring regions. It would be desirable to explore the orientation of Cistercian and early Gothic churches along the Way as well, in order to look for possible persistence and evolutions in these kingdoms.

Author Contributions: Conceptualization, M.U.-A., J.A.B. and A.C.G.-G.; methodology, M.U.-A., J.A.B. and A.C.G.-G.; software, M.U.-A. and A.C.G.-G.; validation, M.U.-A., J.A.B. and A.C.G.-G.; formal analysis, M.U.-A.; investigation, M.U.-A., J.A.B. and A.C.G.-G.; resources, A.C.G.-G.; data curation, M.U.-A. and A.C.G.-G.; writing—original draft preparation, M.U.-A.; writing—review and editing, J.A.B. and A.C.G.-G.; visualization, M.U.-A.; supervision, J.A.B. and A.C.G.-G.; project administration, J.A.B.; funding acquisition, J.A.B. and A.C.G.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the State Research Agency (AEI), the Spanish Ministry of Science, Innovation and Universities (MICIU), and the European Regional Development Fund (ERDF) under grants with references AYA2015-66787-P 'Orientatio ad Sidera IV', PID2020-115940GB-C21, PID2020-115940GB-C22 'Orientatio ad Sidera V' and under the internal IAC project P310793 'Arqueoastronomía' and it is part of the project EIN2020-112463, funded by MCIN/AEI/10.13039/501100022033 and by the European Union "NextGenerationEU"/PRTR".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data complementing the Appendix A can be found at https://arqarqt.revistas.csic.es/index.php/arqarqt/article/view/284 (accessed on 1 January 2022).

Acknowledgments: The authors sincerely appreciate the support of the people at the Instituto de Ciencias del Patrimonio (Incipit-CSIC), as well as the feedback and the rapid response of four external referees. These reviews have helped improve the quality of this paper. The authors would like to acknowledge the crucial help provided by Paz Alonso-Arias and Marina Aparicio Utrera with fieldwork during the Covid-19 pandemic.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Archaeoastronomical data on the Romanesque churches in the kingdoms of Castile (La Rioja), Navarre, and Aragon that traverse the French Way at its eastern part. The columns indicate for each church the ancient Christian kingdom to which it belonged (Kingdom), the place of construction (Place), its consecration (Monument), latitude north (φ), longitude west (λ), azimuth (*a*), height of the horizon in that orientation (*h*), and resultant declination values (δ). Azimuth values are corrected from magnetic variation, and the given errors include the intrinsic instrumental error of ½º and the standard deviation of the measurements. Values of the height of the horizon obtained or revised with HeyWhatsThat have been marked with an asterisk. Finally, the declination errors have been calculated by first correcting the altitude values for atmospheric refraction and then by propagation of errors.

Kingdom	Place	Monument	*φ* (°/′)	*λ* (°/′)	*a* (°)	*h* (°)	*δ* (°)
Castile (La Rioja)	San Vicente del Valle	Ntra Sra de la Asunción	42/20	−3/9	62.1 ± 1.1	11.5	28.2 ± 1.0
	Valgañón	Ntra Sra de las Tres Fuentes	42/19	−3/4	66.8 ± 0.5	0.0	16.5 ± 0.5
	Zorraquín	San Esteban	42/19	−3/2	91.5 ± 1.4	4.5 *	1.8 ± 1.2
	Ojacastro	Ermita de la Ascensión San Asensio de los Cantos	42/22	−2/58	85.7 ± 0.8	17.7 *	14.9 ± 0.7

	Santo Domingo de la Calzada	El Salvador	42/26	−2/57	95.1 ± 0.4	0.3 *	−3.9 ± 0.5
	Ochánduri	Santa María de la Concepción	42/31	−3/0	54.5 ± 0.5	0.5	25.4 ± 0.5
	Cuzcurrita del Río Tirón	Santa María de Sorejana	42/32	−2/58	73.7 ± 0.4	1.0	12.3 ± 0.5
	Tirgo	San Salvador	42/32	−2/56	85.8 ± 0.9	0.4 *	3.0 ± 0.8
	San Vicente de la Sonsierra	Santa María de la Piscina	42/34	−2/43	80.4 ± 0.6	3.5	9.3 ± 0.6
	Ábalos	San Felices	42/34	−2/41	83.1 ± 0.3	−0.5	4.3 ± 0.4
	Leza del Río Leza	Santa María de Plano	42/20	−2/23	79.8 ± 1.1	2.5	9.0 ± 1.0
	Albelda de Iregua	Santa Fe de Palazuelos	42/21	−2/26	71.2 ± 0.3	1.5	14.6 ± 0.4
	La Población de Meano	Ntra Sra de la Asunción	42/36	−2/27	62.4 ± 0.3	1.5	20.8 ± 0.4
	Aguilar de Codés	San Bartolomé	42/36	−2/22	101.4 ± 0.8	7.5	−3.3 ± 0.7
	Azuelo	San Jorge	42/36	−2/20	91.1 ± 0.5	2.0	0.3 ± 0.5
	Torres del Río	Santo Sepulcro	42/33	−2/16	54.7 ± 0.6	7.0	30.2 ± 0.6
	Learza	San Andrés	42/36	−2/10	83.1 ± 0.8	2.0	6.2 ± 0.8
	Olejua	Santiago	42/37	−2/8	67.2 ± 1.0	5.5	20.3 ± 0.9
	Villamayor de Monjardín	San Andrés Apóstol	42/37	−2/6	88.3 ± 1.0	4.0	3.8 ± 0.9
	Irache	Santa María de Irache	42/39	−2/2	89.5 ± 0.8	1.0	0.8 ± 0.8
	Aberin	San Juan Bautista	42/37	−2/0	85.1 ± 0.6	0.5	3.6 ± 0.6
	Estella	San Pedro	42/40	−2/1	91.3 ± 2.2	2.3 *	0.4 ± 1.8
	Estella	Santa María Jus del Castillo	42/40	−2/1	77.5 ± 0.5	4.1 *	11.8 ± 0.5
	Estella	Santo Sepulcro	42/40	−2/1	95.9 ± 1.1	6.3 *	−0.1 ± 1.0
	Estella	San Miguel	42/40	−2/1	89.1 ± 1.1	4.5	3.6 ± 1.0
	Azcona	Santa Catalina de Alejandría	42/44	−1/58	71.0 ± 0.6	1.0	14.2 ± 0.6
	Ugar	San Martín	42/43	−1/58	89.6 ± 0.5	3.3 *	2.4 ± 0.5
	Zurucuáin	San Martín de Montalbán	42/42	−1/58	114.6 ± 0.6	2.0	−16.6 ± 0.6
	Eguiarte	Santa María	42/41	−1/57	91.0 ± 0.6	3.0	1.1 ± 0.6
Navarre	Lácar	Santa Engracia	42/41	−1/57	64.8 ± 0.5	4.1 *	21.0 ± 0.5
	Puente de la Reina	Santiago	42/40	−1/48	76.5 ± 0.3	1.8 *	10.9 ± 0.4
	Puente de la Reina	Crucifijo	42/40	−1/48	65.8 ± 0.9	2.2 *	18.9 ± 0.8
	Muruzábal	Santa María de Eunate	42/40	−1/45	105.1 ± 0.5	2.0	−9.9 ± 0.5
	Olite	San Pedro	42/28	−1/38	88.5 ± 1.7	1.0	1.5 ± 1.4
	Unx	San Martín	42/31	−1/33	76.1 ± 1.0	2.7 *	11.9 ± 0.9
	Ujué	Santa María	42/30	−1/29	90.3 ± 1.3	0.3 *	−0.4 ± 1.1
	Lerga	San Martín	42/33	−1/30	77.3 ± 0.4	2.3 *	10.7 ± 0.5
	Olleta	Ntra Sra de la Asunción de la Virgen	42/35	−1/32	100.6 ± 0.7	7.4 *	−2.8 ± 0.7
	Garínoain	Santo Cristo de Catalán	42/36	−1/37	79.6 ± 0.4	4.0	10.2 ± 0.5
	Orísoain	San Martín	42/36	−1/36	85.9 ± 0.8	6.5	7.3 ± 0.8
	Olóriz	San Pedro ad Vincula de Echano	42/38	−1/35	61.7 ± 0.5	9.5	27.1 ± 0.5
	Zariquiegui	San Andrés	42/44	−1/43	71.1 ± 0.5	0.5	13.8 ± 0.5
	Larraya	San Román	42/46	−1/45	75.3 ± 0.6	2.0	11.9 ± 0.6
	Sagüés	San Miguel Arcángel	42/47	−1/43	80.1 ± 0.5	1.0	7.7 ± 0.5
	Gazólaz	Ntra Sra de la Purificación	42/47	−1/43	75.3 ± 0.6	3.5 *	13.0 ± 0.6
	Cizur Menor	San Emeterio y San Celedonio	42/47	−1/40	94.7 ± 1.0	1.5	−2.7 ± 0.9
	Zolina	San Esteban	42/46	−1/35	73.3 ± 0.6	3.0	14.1 ± 0.6
	Najurieta	Santo Tomás	42/43	−1/29	69.2 ± 0.5	6.0	19.2 ± 0.5

	Artaiz	San Martín de Artaiz	42/44	−1/28	89.5 ± 0.8	1.0	0.8 ± 0.8
	Sangüesa	Santa María la Real	42/34	−1/17	93.8 ± 0.5	2.9 *	−1.0 ± 0.5
	Vadoluengo	San Adrián	42/33	−1/17	102.8 ± 0.6	1.5	−8.6 ± 0.6
	Yesa	San Salvador de Leyre	42/38	−1/10	90.3 ± 0.4	0.7 *	−0.1 ± 0.5
	Sasabe	San Adrián	42/40	−0/35	93.5 ± 0.5	17.0	8.9 ± 0.5
	Acín	San Juan Bautista	42/37	−0/27	83.2 ± 0.4	16.0	15.7 ± 0.5
	Iguácel	Santa María	42/38	−0/28	79.8 ± 0.4	17.75	19.3 ± 0.5
	Castiello de Jaca	Santa Juliana	42/37	−0/32	65.5 ± 0.7	8.5	23.6 ± 0.7
	Navasa	Santa Eulalia	42/31	−0/28	110.5 ± 0.5	3.5 *	−12.6 ± 0.5
	Barós	Santiago	42/32	−0/31	85.7 ± 0.8	1.5	3.9 ± 0.8
	Barós	San Fructuoso	42/32	−0/31	104.8 ± 0.8	1.5	−10.1 ± 0.8
	Jaca	San Pedro	42/34	−0/32	94.1 ± 0.3	1.6 *	−2.2 ± 0.4
	Binacua	Ángeles Custodios	42/32	−0/41	97.7 ± 0.4	2.5	−4.1 ± 0.5
	Santa Cruz de la Serós	San Caprasio	42/31	−0/40	105.9 ± 0.4	10.5	−4.4 ± 0.5
	Santa Cruz de la Serós	Santa María	42/31	−0/40	103.4 ± 0.7	11.5	−1.9 ± 0.7
	Botaya	San Miguel	42/29	−0/38	92.9 ± 1.1	13.0	6.6 ± 1.0
	Banaguás	San Juan Bautista	42/34	−0/35	99.8 ± 0.3	2.0	−6.0 ± 0.4
	Asieso	San Andrés	42/34	−0/33	80.2 ± 0.2	4.0	9.8 ± 0.3
Aragon	Loarre	San Pedro	42/19	−0/36	83.6 ± 0.7	5.5 *	8.3 ± 0.7
	Loarre	Santa María de Valverde	42/19	−0/36	83.5 ± 0.7	5.5 *	8.4 ± 0.7
	Agüero	San Salvador	42/21	−0/47	91.9 ± 0.7	4.0	1.2 ± 0.7
	Agüero	Santiago	42/20	−0/47	109.1 ± 3.8	1.5	−13.2 ± 2.9
	Murillo de Gállego	San Salvador	42/20	−0/45	93.9 ± 0.4	7.5 *	2.1 ± 0.5
	Riglos	San Martín	42/20	−0/43	105.1 ± 0.9	12.0	−2.8 ± 0.8
	Concilio	Santa María	42/18	−0/44	100.4 ± 0.5	5.0	−4.4 ± 0.5
	Uncastillo	San Juan	42/21	−1/8	83.2 ± 0.6	5.0	8.3 ± 0.6
	Uncastillo	San Martín	42/21	−1/7	103.4 ± 0.5	7.5	−4.8 ± 0.5
	Uncastillo	Santa María la Mayor	42/21	−1/7	73.3 ± 0.4	6.4 *	16.5 ± 0.5
	Uncastillo	San Felices	42/21	−1/8	102.8 ± 0.3	5.1 *	−6.0 ± 0.4
	Luesia	San Salvador	42/22	−1/1	101.4 ± 0.9	3.4 *	−6.2 ± 0.8
	Luesia	San Esteban	42/22	−1/1	80.5 ± 0.2	5.0	10.3 ± 0.3
	Urriés	San Esteban	42/31	−1/7	98.7 ± 0.7	4.2 *	−3.7 ± 0.7
	Navardún	Ntra Sra de la Asunción	42/30	−1/8	94.3 ± 0.5	3.4 *	−1.0 ± 0.5
	Sos–Ceñito	San Nicolás	42/30	−1/7	83.2 ± 0.5	3.5	7.2 ± 0.5
	Sos del Rey Católico	San Esteban	42/29	−1/12	102.4 ± 0.3	1.0	−8.7 ± 0.4

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