The Milky Way: Mobility and Economy at the Turn of the 3rd Millennium in Southern Central Europe

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APPENDIX S1: INFORMATION ON CHAM CULTURE ANIMAL BONE AND PLANT ASSEMBLAGES

Daniela Hofmann

TABLE S1.1: PERCENTAGES OF ANIMAL SPECIES RECORDED FOR CHAM CULTURE SITES.

Note the different methods of quantification used. Percentages in square brackets were not provided by the authors but extrapolated from available information. Where NISP values are marked by a star, there were discrepancies between sources in the NISP reported (eg, between von den Driesch 2004; Ganslmeier 2001 and the original reports), figures in the original reports have been privileged. In general, the domesticate status of horse is considered uncertain at this time; here, horses have been classed as a wild species, with the exception of Galgenberg, where a case is made for an early domesticated herd (see main text).

Site and reference	*Species*	%	*Method of quantification*
Aiterhofen (Hanöffner & Siftar 2007, 101)	Domesticates: cattle dominate, followed by pig, sheep/goat & dog		no numerical data given
	Large wild animals: red deer dominates, increase in horse compared to previous periods, also roe deer, boar & one wolf bone		
	Aquatic resources: one freshwater shell		
Burgwiese (Schmitzberger 2008)	Domesticates: cattle 44.9%, sheep/goat 12%, pig 21%, dog 1.3%	79.2%	NISP, n=534 (excluding fish)
	Large wild animals: red deer 14.6%, boar 4.1%, roe deer 0.9%	19.6%	
	Small wild animals: fox 0.4%, beaver 0.7%	1.1%	
	Fish: 207 fish bones & scales, mainly carp (Galik 2008)		
Dietfurt (König 1993; site is named Griesstetten there)	Domesticates: cattle (53.5%), pig (9.2%), sheep/goat (5.6%), dog (0.4%)	68.7%	* NISP, n=12,697 (those designated as 'wild or domestic' are excluded, with the exception of horse)
	Large wild animals: red deer (24%), boar (3.3%), roe deer (1.1%), aurochs (1.1%), horse (0.9%), bear (0.3%)	29.6%	
	Small wild animals: beaver (0.5%), isolated bones of wolf, hare, otter, fox, wild cat, fish (together 0.2%)	0.7 %	
Dobl (Uerpmann 1988)	Domesticates: Sheep/goat 35.2%, cattle 17.6 %, pig 6.7%	59.5%	NISP, n=165 (weight 0.93 kg); missing percentages are 'wild or domestic'
	Large wild animals: red deer 17%, boar 2.4%, elk 0.6%, horse 0.6%, wolf 0.6%	21.2%	
	Small wild animals: beaver 3%	3%	

Site and reference	*Species*	*%*	*Method used*
Galgenberg (Glass 1999)	Domesticates: horse 22.5%, dog 14.1%, cattle 10.6%, sheep/goat 7%, pig 6.2%	60.4%	NISP, n=8620 (weight 88.9 kg), but percentages calculated based on identified taxa, n=2197; missing percentages are 'wild or domestic'
	Large wild animals: red deer 14.4%, boar 6.2%, roe deer 2.9%, aurochs 0.6%, bear 0.4%	24.5%	
	Small wild animals: beaver 0.8%, badger 0.3%, birds 0.3%, fox 0.2%, squirrel 0.05%, marten 0.05%, hare 0.05%	1.8%	
	Aquatic animals: amphibians 1.9%, turtle 0.1%, fish 0.1%	2.1%	
Hadersbach (von den Driesch 2004)	Domesticates: cattle, sheep/goat, pig, dog (in order of frequency)	[70.3%]	NISP, n=401
	Wild animals: species not listed	29.7%	
Hienheim (Clason 1977)	Domesticates: cattle 22.2%, pig 14.8%, sheep/goat 3.7%, dog 3.7%	44.4%	NISP, n=18; missing percentages are 'wild or domestic'
	Wild animals: 1 piece of antler (3.7%)	3.7%	
Hinterer Berg (Bogner 2017)	Domesticates: sheep/goat (46.7%), pig (33%), cattle (6.7%)	86.4%	NISP, n=15
	Large wild animals: roe deer, red deer (each 6.7%)	13.4%	
Köfering (Ganslmeier 2001)	Domesticates: cattle, sheep/goat, pig (relative frequencies not reported)	92%	NISP, n=23
	Wild animals: species not listed	8%	
Mintraching-Moosham (Boessneck & Schäffer 1985)	Domesticates: cattle (21.4%), sheep/goat (21.4%)	42.8%	* NISP, n=14 (those designated as "wild or domestic" are excluded, with the exception of horse)
	Large wild animals: horse (28.6%), red deer (21.4%), roe deer (7.1%)	57.1%	
Oberschneiding (von den Driesch 2004)	Domesticates: cattle, sheep/goat, pig, dog (in order of frequency)	[83.7%]	NISP, n=129
	Wild animals: species not listed	16.3%	
Riedling (Ewersen in prep.)	Cattle (75%); sheep/goat (13.6%); pig (11.4%); cattle or deer (2.3%)		NISP, n=44; no distinction domestic/wild possible for cattle & pig
Riekofen-Kellnerfeld (Busch 1985)	Domesticates: pig (30.7%), cattle (16.2%), sheep/goat (12%), dog (0.8%)	59.7%	* NISP, n=11,021 (those designated as 'wild or domestic' are excluded, with the exception of horse)
	Large wild animals: red deer (17.2%), boar (7.9%), roe deer (2.9%), horse (2.9%), bear (0.6%), aurochs (0.4%), elk (0.1%), single bone of wolf	32%	
	Small wild animals: beaver (0.9%), squirrel (0.2%), wild cat (0.2%), marten (0.2%), fox (0.1%), single bones of hare, hedgehog & badger. Various species of bird (0.4%),	2 %	
	Aquatic resources: frog & toad (1.2%), fish (2%), single bones of pond turtle	3.2 %	
Stephansposching Wischlburg (Manhart 2004)	Domesticates: cattle 68.1%, sheep/goat 5.6%, pig 6.2%, dog 2.5%	82.4%	NISP, n=160 (weight 9.2kg); missing percentages are "wild or domestic"
	Large wild animals: horse 7.5%, red deer 3.8%, boar 1.9%, bear 0.6%, aurochs 0.6%	14.4%	

TABLE S1.2: PLANT REMAINS RECORDED FOR CHAM CULTURE SITES

Site & reference	*Plants attested*	*Method used*
Burgwiese (Wietholt & Wähnert 2008)	emmer & einkorn dominate, next frequent is naked barley. Some strawberry & hazelnut & some weeds (incl. *Chenopodium album*)	Flotation of 107 litres (634 remains)
Dobl (Hopf 1988)	naked barley (×8), spelt wheat (×2), einkorn (×1)	Impressions on pottery
Galgenberg (Hinton 1999)	hulled barley dominates, followed by emmer, einkorn, naked wheat, pea & flax	Flotation of 176 litres (1695 remains)
Hadersbach (Küster 1995, 80)	mostly indeterminate cereals; definitely attested: barley, emmer, einkorn, spelt, flax, pea, hazelnut, *Chenopodium album*	Flotation (163 remains)
Riekofen (Matuschik 1999)	barley dominates, but emmer & einkorn are also attested	Impressions on pottery
Wischlburg (Peters 2004)	barley dominates, followed by emmer & einkorn; there are also hazelnut, *Chenopodium album*, elderberry	Flotation of 18 samples

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APPENDIX S2: METHODS

Organic residue analysis

(Julie Dunne)

Lipid analysis and interpretations were performed using established protocols described in detail in earlier publications (Correa-Ascencio & Evershed 2014). Briefly, ~2 g of potsherds were sampled and surfaces cleaned with a modelling drill to remove exogenous lipids. The cleaned sherd powder was crushed in a solvent-washed mortar and pestle and weighed into a furnaced culture tube (I). An internal standard was added (20 µg *n*-tetratriacontane; Sigma Aldrich Company Ltd) together with 5 mL of H_2SO_4/MeOH (2– 4% v/v, $\delta^{13}C$ value measured) and the culture tubes were placed on a heating block for 1 hour at 70°C, mixing every 10 minutes. Once cooled, the methanolic acid was transferred to test tubes and centrifuged at 2500 rpm for 10 min. The supernatant was then decanted into another furnaced culture tube (II) and 2 mL of DCM extracted double distilled water was added. To recover any lipids not fully solubilised by the methanol solution, 2 × 3 mL of *n*-hexane was added to the extracted potsherds contained in the original culture tubes, mixed well and transferred to culture tube II. The extraction was transferred to a clean, furnaced 3.5 mL vial and blown down to dryness. Following this, 2 × 2 mL *n*-hexane was added directly to the H_2SO_4/MeOH solution in culture tube II and whirlimixed to extract the remaining residues, then transferred to the 3.5 mL vials and blown down until a full vial of *n*-hexane remained. Aliquots of the extracts (containing fatty acid methyl esters, FAME's) were derivatised using *N,O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% *v/v* trimethyl-chlorosilane (TMCS; Sigma Aldrich Company Ltd; 20 µL; 70°C, 1 h). Excess BSTFA was removed under nitrogen and the extract was dissolved in *n*-hexane for analysis by gas chromatography (GC), GC–mass spectrometry (GC–MS) and GC–combustion–isotope ratio MS (GC–C–IRMS).

Lipid extracts were also investigated using GC/MS-SIM for high-sensitivity detection of ω-(o-alkylphenyl) alkanoic acids (APAAs) and dihydroxy acids (DHFAs).

First, the samples underwent high-temperature gas chromatography using a gas chrom-ategraph (GC) fitted with a high temperature non-polar column (DB1-HT; 100% dimethylpolysiloxane, 15 m × 0·32 mm i.d., 0.1 µm film thickness). The carrier gas was helium and the temperature programme comprised a 50°C isothermal hold followed by an increase to 350°C at a rate of 10°C min^{-1} followed by a 10 min isothermal hold. A procedural blank (no sample) was prepared and analysed alongside every batch of samples. Further compound identification was accomplished using gas chromatography-mass spectrometry (GC-MS). FAMEs were then introduced by autosampler onto a GC-MS fitted with a non-polar column (100% dimethyl polysiloxane stationary phase; 60 m × 0.25 mm i.d., 0·1 µm film thickness). The instrument was a ThermoFinnigan single quadrupole TraceMS run in EI mode (electron energy 70 eV, scan time of 0·6 s). Samples were run in full scan mode (*m*/*z* 50–650) and the temperature programme comprised an isothermal hold at 50°C for 2 min, ramping to 300°C at 10°C min^{-1}, followed by an isothermal hold at 300°C (15 min). Data acquisition and processing were carried out using the HP Chemstation software (Rev. C.01.07 (27), Agilent Technologies) and Xcalibur software (version 3.0). Peaks were identified on the basis of their mass spectra and GC retention times, by comparison with the NIST mass spectral library (version 2.0).

Carbon isotope analyses by GC-C-IRMS were also carried out using a GC Agilent Technologies 7890A coupled to an Isoprime 100 (EI, 70eV, three Faraday cup collectors *m*/*z* 44, 45 and 46) via an IsoprimeGC5 combustion interface with a CuO and silver wool reactor maintained at 850°C. Instrument accuracy was determined using an external FAME standard mixture (C_{11}, C_{13}, C_{16}, C_{21} and C_{23}) of known isotopic composition. Samples were run in duplicate and an average taken. The $\delta^{13}C$ values are the ratios $^{13}C/^{12}C$ and expressed relative to the Vienna Pee Dee Belemnite, calibrated against a CO_2 reference gas of known isotopic composition. Instrument error was ±0.3‰. Data processing was carried out using Ion Vantage software (version 1.6.1.0, IsoPrime).

Compound-specific radiocarbon analyses

(Emmanuelle Casanova)

Compound-specific radiocarbon analyses of organic residues extracted from archaeological potsherds were performed using established protocols described in detail in recent publications (Casanova *et al*. 2017; 2018; 2020). A piece of ~2 g of potsherd was sampled and extracted into a culture tube (I) using H_2SO_4/MeOH (4% *v/v*, 3 × 8 mL, 70°C, 1 h). The supernatant was centrifuged (2500 rpm, 10 min) and combined into a second culture tube (II) containing double-distilled water (5 mL). The lipids were extracted with *n*-hexane (4 × 5 mL) and blown down to dryness at room temperature under a gentle nitrogen stream into a 3.5 mL vial. Then an appropriate amount of *n*-hexane was added for isolation in PCGC.

The PCGC consisted of a Hewlett Packard 5890 series II gas chromatograph coupled to a Gerstel Preparative Fraction Collector by a heated transfer line. The GC was equipped with a column with a 100% poly(dimethyl siloxane) stationary phase (Rxi-1ms, 30 m × 0.53 mm i.d., 1.5 μm film thickness, Restek). Helium was used as a carrier gas at a constant pressure of 10 psi. The GC temperature programme started with an isothermal hold at 50°C for 2 min, increased to 200°C at 40°C min^{-1}, then increased to 270°C at 10°C min^{-1} and finally increased to 300°C at 20°C min^{-1} and held for 8.75 min. FAMEs were injected (40 × 1 μL per run) in the column and passed via a transfer line into the preparative fraction collector, both heated to 300°C. The C_{16} and C_{18} FAMEs were isolated based on their retention times (Casanova *et al*. 2018; 2020) and separated into individual solventless traps.

PCGC isolated samples were transferred into Al capsules then combusted to CO_2 in an Vario Microcube Elemental Analyser linked to an Automated Graphitisation System (AGE 3; Wacker *et al*. 2010a; 2010b). All the radiocarbon determinations were performed on a MICADAS AMS (Synal *et al*. 2007) by the Bristol Accelerator Mass Spectrometer (BRAMS) facility at the University of Bristol. Data reduction was performed using the software package BATS (Wacker *et al*. 2010b).

The C_{16} and C_{18} FAMEs dates were combined before calibration (Casanova *et al*. 2020) in OxCal v4.3 (Bronk Ramsey 2009) against the currently internationally agreed radiocarbon calibration curve for the northern hemisphere, IntCal20 (Reimer *et al*. 2020).

Chronological modelling of Cham culture dates

(Seren Griffiths)

The legacy data that were included in this analysis were often not published with important details including the dated sample and isotopic information (e.g. $\delta^{13}C/\delta^{15}N$, C:N ratio, etc). Nevertheless, we feel that the data can provide an initial indication of the duration of Cham material culture in southern Bavaria.

We have identified 62 measurements from 13 sites which we believe to be accurate estimates for the use of Cham pottery (see Appendix S3). We have applied two approaches to the data using the programme OxCal (Bronk Ramsey 2009). First, where there are sufficient measurements (usually four or more) results have been presented in a site-specific model adapting the notation:

```
Sequence() { Boundary("Start site name"); Phase("name") {…}; Boundary("End
site name"); };
```

Samples on unidentified charcoal have been presented using a formal charcoal outlier approach (Dee & Bronk Ramsey 2014) and are defined as being older than the contexts from which they were recovered. This is because samples of charcoal and wood can be already old when they enter the archaeological record ('old wood effect').

The second approach works only with samples on short-life materials. In this approach we have applied a Kernel Density Estimate (Bronk Ramsey 2017) to summarise the dataset. We present this to complement the site-specific modelling. Applying these complementary approaches can provide a useful different perspective when investigating evidence for change in the archaeological record (Griffiths *et al*. 2022). The OxCal CQL2 keywords and the brackets shown in the figures define the modelling approach presented here, as does the code in Appendix S4.

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APPENDIX S3: ^{14}C DATES ASSOCIATED WITH CHAM CULTURE MATERIAL

(Daniela Hofmann and Seren Griffiths)

TABLE S3.1. RADIOCARBON LEGACY RESULTS ASSOCIATED WITH CHAM CULTURE MATERIALFROM BAVARIA, TOGETHER WITH THE NEW DATA ASSOCIATED WITH CHAM POTTERY FROM RIEDLING (AT THE BOTTOM OF THE TABLE). MH = MÜNCHSHÖFEN

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*$\delta^{13}C/\delta^{15}N$ (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Aiterhofen-Ödmühle (Hanöffner & Siftar 2007)						
Hd 15029-15543	4444±31	Animal bone		Feature 196: pit with Cham pottery. In general pottery is thought to be Mid–Late Cham, but there are some vessels with possible early elements.		Dates activity associated with use of Cham pottery.
Hd 15057-15673	4335±36	Animal bone		Feature 93: pit with Cham pottery; see above.		As above
Hd 15058-15164	4658±43	Animal bone		Feature 94: pit with Cham pottery & Corded Ware Beaker. Assemblage includes residual material.		Not included in model; deposit includes mixed assemblage of residual material.
Dietfurt a.d. Altmühl (Gohlisch 2005)						
Erl-2143	4048±88	Animal bone		Pit 4, lower part of fill. At 40 cm, this was one of the deepest features on site, & very finds-rich. The pottery is exclusively Cham, & the fill structure homogeneous with no clear layering. No later disturbance visible.	The site dates to the later Cham on typological grounds; there is also 1 Corded Ware beaker. There were at least 2 phases, given the superposition of stone pavings & features, but it is unclear whether there was a temporal gap. There are few cut features, making it difficult to assign material culture (generally recovered from a 'cultural layer' or spread of material) to a settlement phase. The site was flooded by the river for a time, ending	Dates activity associated with use of Cham pottery.
Erl-2144	4089±90	Animal bone		Pit 4, middle part of fill. Description see above.		As above
Erl-2145	4129±110	Animal bone		Pit 4, middle part of fill. Description see above.		As above
Erl-2146	4257±54	Bone tool (frag. chisel,		Cultural layer in Zone 1.		As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ*[13]*C/δ*[15]*N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
		deer metapodial)			occupation. The conventional dates from Hanover were commissioned during the excavation & without a clear strategy & from site zones 3 & 4 in the eastern part of the excavation. In 1999, the Erlangen dates covering the western zones 1 & 2 were collected from typologically diagnostic bone tools & from one pit with only Cham pottery.	
Erl-2147	4440±56	Bone tool (chisel, deer metatarsal)		Cultural layer in Zone 1.		As above
Erl-2148	3989±53	Bone tool (chisel, species unknown)		Cultural layer in Zone 1.		As above
Hv-17223	3985±280	Charcoal		Pit 81 – shallow & amorphous depression, depth *c.* 10 cm. Probably part of the cultural layer, rather than a cut feature.		Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
Hv-17224	4360±175	Charcoal		Pit 151 – depression with fuzzy edges, *c.* 15 cm deep. In its centre, about 5–6 cm below the surface, was a charcoal concentration from which the date comes. The remainder of the fill was homogeneous, with the exception of some daub clusters.		As above
Hv-17225	4175±130	Charcoal		Pit 86 – round shallow pit (15 cm deep) with homogeneous fill from which a bulk charcoal date was collected. The pit is partly overlain by a stone paving, so is not the latest settlement phase.		As above
Hv-17226	4315±75	Charcoal		Pit 52 – *c.* 25 cm deep pit rich in finds. Unidentified charcoal was collected from near the base of the feature.		As above
Hv-17227	1860±55	Charcoal from charred post		Posthole 5 – contained both small Neolithic sherds & others, fired at a		As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ¹³C/δ¹⁵N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
				much higher temperature & probably not (or very late) prehistoric. The post was charred *in situ*.		
Hv-17228	4245±145	Charcoal		Pit 48 – amorphous pit; one side has a darker fill & is deeper (*c.* 30 cm), the date was taken from a charcoal concentration at the base of this deeper section. The pottery is Cham.		As above
Hv-17229	4105±105	Charcoal		Stone paving 148 or pit 153. Stone paving 148 consists of several layers of stone & burnt daub surfaces. In its earliest iteration, there was a semi-circular paved annex, below which lay pit 153. The charcoal for dating probably came from the pit fill (but was recorded as belonging to 148). The pottery in both features is Cham.		As above
Hv-17230	3490±170	Charcoal		Pit 138 – about 25 cm deep, with a darker sediment in the lower half of the fill, from which the charcoal came. However, high proportions of clay & molluscs suggest that flooding played a part in fill formation, so the association of charcoal & feature is tenuous. Finds are mostly from the later part of the Neolithic, with one later sherd.		As above
Hv-17231	4080±135	Charcoal		Tree throw 129. No association of the charcoal with datable pottery.		As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ13C/δ15N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Prutting- Dobl (Burger 1988, 281)						
GrN-7798	4150±60	Charcoal		Dark, charcoal-rich band near base of ditch in segment 1, trench 10. Depth below surface *c.* 1 m.	Later part of Cham. Apart from a few dark bands of charcoal, the ditch fill is homogeneous & contains large, unabraded sherds, so the ditch was probably infilled quickly.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
GrN-7799	4240±60	Charcoal		'Destruction layer' of burnt daub & charcoal in the middle of the ditch fill of segment 3, trench 10 (roughly 1.5 m below surface).		As above
Hinterer Berg bei Landersdorf (Dollhopf 2006)						
Erl-4775	4241±33	Animal bone		Pit 1, layer 2, from which the majority of finds (all Cham culture) also come. This layer is the product of erosion from the pit sides & may have accumulated over some months/years. The sample came from a depth of 70–90 cm below the surface. The top 30 cm of the fill are cut by a later posthole, but this has not impacted layer 2.	Later part of Cham. Two ditches sealing off a promontory. The dates come from the first campaign of excavation, which targeted individual features with Cham material. On the basis of low feature density & typologically homogeneous material, the Cham occupation is believed to be short, but there was later use of the site in the Urnfield period. All samples were taken on single bones, but it is not clear what species.	Dates activity associated with use of Cham pottery
Erl-4776	4205±53	Animal bone		Pit 2, layer 2, *c.* 11–30 cm below surface. More than half of the finds from this pit came from this thick, ashy layer, which appears to be an anthropogenic deposit. There are refitting parts of a bone tool in this & the basal loam layer 1, which probably relates to the primary use of the feature. This means		As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*$\delta^{13}C/\delta^{15}N$ (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
				that layer 2 was formed soon after. Most of the finds were in the upper half of this layer, all are Cham.		
Erl-4777	4224±54	Animal bone		Pit 2, layer 2, *c*. 56–66 cm below the surface; otherwise see above.		Dates activity associated with use of Cham pottery.
Erl-4778	3217±53	Animal bone		Pit 3, layer 4, between 45–82 cm below the surface. This sample has low collagen yield & is considered unreliable in the publication. Description of layer, see below.		Not included in the model as thought not to represent an accurate measurement.
Erl-4779	4142±51	Animal bone		Pit 3, layer 4, *c*. 85 cm below the surface. Loamy layer with limestone blocks (the natural here is limestone), probably natural erosion from the pit sides in the middle third of this feature. The majority of the finds come from this layer, all are Cham.		Dates activity associated with use of Cham pottery.
Erl-4780	4183±50	Animal bone		Pit 4, sediment zone 3, *c*. 85 cm below the surface. The base of the pit had large chunks of charcoal & burnt daub in it. Then a series of fills, first with very little limestone, then with medium limestone blocks, but lying flat (so possibly fast formation, also supported by refits between layers 2 & 3). All finds are Cham.		As above
Erl-4781	3821±48	Animal bone		Pit 4, sediment zone 3, *c*. 85 cm below the surface. This sample had low collagen yield & is therefore considered unreliable in the publication.		Not included in model as thought to not represent an accurate measurement.

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ^{13}C/δ^{15}N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Erl-4782	4254±51	Animal bone		Pit 4, sediment zone 3, *c*. 85 cm below the surface. The base of the pit had large chunks of charcoal & burnt daub in it. Then a series of fills, first with very little limestone, then with medium limestone blocks, but lying flat (so possibly fast formation, also supported by refits between layers 2 & 3). All finds are Cham.		Dates activity associated with use of Cham pottery.
Geibenstetten, Dürnbucher Forst (Teegen* et al. *2019)						
GrA-69102	4480±35	Charcoal		Ditch 2.	Sondage through a pair of ditches with pottery consistent with Cham, but not attributable to a specific phase.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
GrA-69103	4355±35	Charcoal		Ditch 3.		As above
Hienheim (Modderman 1977; 1986; Engelhardt 2011)						
GrN-5732	4220±55	Charcoal		Inner ditch, sample on bulk charcoal.	Earlier Cham.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
GrN-6425	4340±40	Charcoal		Pit 367, sample on bulk charcoal.	Earlier Cham.	As above
GrN-7159	3885±40	Charcoal		Pit 177, sample on bulk charcoal.	Earlier Cham.	As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ13C/δ15N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
GrN-7556	4430±45	Bone		Storage Pit 1343.	Earlier Cham.	Dates activity associated with use of Cham pottery.
GrN-8689	4305±35	Charcoal		Storage Pit 1043, sample on bulk charcoal.	Earlier Cham.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
Köfering (Koch & Wolf 2013)						
Erl-16798	4204±44	Human bone, 8–10 year old child		Grave 44, buried with lithics.	Grave just to the north of the Cham enclosure at Scharwerkbreite. Unclear if this is very late Cham, or Corded Ware re-use. The publication is also not entirely clear on which date was taken on which individual.	Not included in model as uncertain association with Cham pottery.
Erl-16799	4144±41	Human bone, *c.* 4 year old child		Grave 43, buried with lithics.		As above
Galgenberg/Kopfham (Ottaway 1999)						
GrN-12561	4255±40	Charcoal		Base of earliest ditch phase.	Early to Middle Cham.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
GrN-12562	4290±45	Charcoal		Base of last recut of 'forework', an independent short section of ditch in front of the main enclosure.	Early to Middle Cham.	As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ¹³C/δ¹⁵N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
GrN-12563	4150±60	Charred branch		From second recut of ditch.	Early to Middle Cham.	As above
GrN-12564	4210±60	Charred branch		From second recut of ditch.	Early to Middle Cham.	As above
GrN-12699	4510±30	Charcoal		Post which collapsed into earliest phase of ditch.	Early to Middle Cham.	As above
GrN-12700	4225±30	Charred branch		Within earliest ditch phase.	Early to Middle Cham.	As above
GrN-12701	4280±35	Charred branch		From first recut of ditch.	Early to Middle Cham.	As above
GrN-12702	4385±35	Charcoal		From first recut of ditch.	Early to Middle Cham.	As above
GrN-14426	4420±35	Charcoal		Burning horizon (top of earliest ditch phase).	Early to Middle Cham.	As above
GrN-14427	4245±50	Charred branch		Burning horizon (top of earliest ditch phase).	Early to Middle Cham.	As above
GrN-14428	4500±80	Charcoal		Burning horizon (top of earliest ditch phase).	Early to Middle Cham.	as above
GrN-14429	4310±60	Charred stake		Near base of earliest ditch phase, charred stake embedded in gravel.	Early to Middle Cham.	As above
UB-2551	4285±85	Charred stake		Burning horizon (top of earliest ditch phase).	Early to Middle Cham.	As above
Moosham (Engelhardt 2011)						
Hd-8113	4180±65	Charcoal		Ditch 1, Early Cham.	Early Cham.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
Hd-8114	4230±60	Charcoal		Ditch 1, Early Cham.		As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ¹³C/δ¹⁵N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Hd-8112-8173	2835±35	Charcoal		n/a	n/a	Measurements of a very different age from others associated with Cham pottery. Not regarded as an accurate age estimate & not included in the modelling approach presented here.
Hd-8115-8186	5500±60	Charcoal		n/a	n/a	
Hd-8116-8186	6110±55	Charcoal		n/a	n/a	
Hd-8117-8193	5810±35	Charcoal		n/a	n/a	
Oberschneiding (Matuschik 1985)						
H-7442	4350±40	Charcoal		Pit 1.	Early Cham material, apparently associated with a burning layer/destruction horizon.	Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
H-7443	4170±70	Charcoal		Ditch 34.	Early Cham material.	As above
Piesenkofen (Steinmann 2013 and pers. comm)						
Erl-17934	4022±48	Animal bone		Ditch section 40.	Upper infill of ditch, later than destruction horizon.	Dates activity associated with Cham pottery use.
Erl-17935	4414±47	Animal bone		Ditch section 40.	Base of ditch, Early Cham.	As above
Erl-17936	4342±48	Animal bone		Ditch section 40.	Early Cham material.	As above
Erl-17937	4343±48	Animal bone		Ditch section 57.	Early Cham material.	As above
Erl-17938	4230±49	Animal bone		Ditch section 60.	Recut in ditch, when a prior causeway was dug away.	As above
Erl-17941	4483±49	Animal bone		Pit 26.	Early Cham, pit S of enclosure.	As above
Erl-17942	4142±48	Animal bone		Pit 63.	Middle Cham, pit W of enclosure.	As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ¹³C/δ¹⁵N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Riekofen Kellnerfeld (Matuschik & Werner 1986)						
H-7409	4252±35	Unclear		Enclosure A, ditch 1.	Ditch 1 is the inner of a pair of Neolithic ditches with Middle to Late Cham material, but there is little detail where The dates came from in relation to the stratigraphy. Quoted measurements are inconsistently cited in different publications (cf. Matuschik *et al*. 2001), but differences are minor. We have here chosen to follow the first publication as less likely to contain typos associated with later re-use of the data.	Inconsistent results quoted; not included in the model.
H-7411	4307±45	Charcoal		Enclosure A, ditch 1.		As above
H-7412	4327±35	Charcoal		Wall trench 73.		As above
H-7410	4692±30	Charcoal		Enclosure A, ditch 1.		Dates activity associated with use of Cham pottery. May include an 'old wood' effect. Included as a charcoal outlier, as part of the charcoal outlier model.
Stephansposching-Wischlburg (Schmotz 2004)						
KIA-21412	4225±46	Animal bone		Ditch 120 (outermost ditch), near base, from a layer with daub & charcoal. The ditch was still 1.2 m deep.	Set of 3 ditches with Late Cham material.	Dates activity associated with Cham pottery use.
KIA-21413	4378±37	Animal bone		Ditch 127 (innermost of the set), from a loose spread of sherds & bone at the base of a recut in this ditch. Animal bones looked unweathered.		As above
Riedling						
Poz-115527	4385±35	Mandible of domesticated pig		Section through ditch B, depth *c*. 10–30 cm. Feature with mixed MH & Cham pottery.	Mixed assemblage.	Not included in model as uncertain association with Cham pottery.
Poz-115528	4390±30	Cervical vertebra of domesticated cattle		Section through ditch B, depth *c*. 10–30 cm. Feature with mixed MH & Cham pottery.	Mixed assemblage.	As above

Lab. no	*Radiocarbon age (BP)*	*Radiocarbon sample*	*δ¹³C/δ¹⁵N (‰) C:N ratio*	*Context details*	*Association with diagnostic material culture*	*Interpretation of chronological data & treatment in model*
Poz-115693	4120 ±40	Cattle tooth (index no. 457)	4.5‰C, 0.9‰N, 0.4mgC	Pit 580. A depression at the base of pit house 575. The house is *c.* 70 cm deep & cuts pit 495 as well as section 420/578 of ditch A (Münchshöfen culture).	Cham culture.	Later than other results from Cham culture contexts from this site. May not represent accurate estimate for Cham activity. Not included in the model.
BRAMS-3703	4383±30	Lipid sample no. 105 from cup with wavy rim (Wellen-randtasse)		Pit house 471. Rectangular, semi-subterranean pit hut. Cuts pit 475.	Cham culture.	Direct date for Cham pottery use.
BRAMS-3702	4394±22	Lipid sample no. 068 from conical cup		Pit house 108. Rectangular semi-subterranean pit-house with several depressions at its base. Depth *c.* 40 cm.	Cham culture.	As above
BRAMS-4382	4366±22	Lipid sample no. 065 from conical cup		Pit house 108. Rectangular semi-subterranean pit-house with several depressions at its base. Depth *c.* 40 cm.	Cham culture.	As above
BRAMS-4383	4398±22	Lipid sample no. 088 from funnel-necked pot		Pit house 252. Rectangular semi-subterranean pit house with flat base, depth *c.* 30 cm. Cuts pit 370.	Cham culture.	As above

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APPENDIX S4: OXCAL CHRONOLOGICAL CODE USED IN THE BAYESIAN ANALYSIS OF RADIOCARBON DATES

(Seren Griffiths)

```
Plot()
 {
  //please cite as Griffiths in Dunne et al. The Milky Way: Mobility and economy at the turn of the third millennium in southern central Europe.
  Outlier_Model("Charcoal",Exp(1,-10,0),U(0,3),"t");
  Sequence()
  {
   Boundary("Start_Cham");
   Phase("Cham")
   {
    KDE_Plot("Cham_Bavaria", )
    {
    };
    First("first_Cham_Bavaria");
    Last("last_Cham_Bavaria");
    Span("duration_Cham");
    Phase("Aiterhofen Oedmuehle")
    {
     R_Date("Hd-15029-15543", 4444, 31);
     R_Date("Hd-15057-15673", 4335, 36);
     //assemblage includes residual material Hd-15058-15164, 4658, 43
    };
    Sequence()
    {
     Boundary("Start Dietfurt Altmuehl Stadt");
     Phase("Dietfurt Altmuehl Stadt")
     {
      R_Date("Erl-2143", 4048, 88);
      R_Date("Erl-2144", 4089, 90);
      R_Date("Erl-2145", 4129, 110);
      R_Date("Erl-2146", 4257, 54);
      R_Date("Erl-2147", 4440, 56);
      R_Date("Erl-2148", 3989, 53);
      R_Date("Hv-17223", 3985, 280)
      {
       Outlier(1);
      };
      R_Date("Hv-17224", 4360, 175)
      {
       Outlier(1);
      };
      R_Date("Hv-17225", 4175, 130)
      {
       Outlier(1);
      };
```

```
  R_Date("Hv-17226", 4315, 75)
  {
   Outlier(1);
  };
  //not included as much later not an accurate estimate for Cham pottery use Hv-17227, 1860, 55
  R_Date("Hv-17228", 4245, 145)
  {
   Outlier(1);
  };
  R_Date("Hv-17229", 4105, 105)
  {
   Outlier(1);
  };
  R_Date("Hv-17230", 3490, 170)
  {
   Outlier(1);
  };
  R_Date("Hv-17231", 4080, 135)
  {
   Outlier(1);
  };
 };
 Boundary("End Dietfurt Altmuehl Stadt");
};
Phase("Dobl")
{
 R_Date("GrN-7798", 4150, 60)
 {
  Outlier(1);
 };
 R_Date("GrN-7799", 4240, 60)
 {
  Outlier(1);
 };
};
Phase("Geibenstetten, Duernbucher Forst")
{
 R_Date("GrA-69102", 4480, 35)
 {
  Outlier(1);
 };
 R_Date("GrA-69103", 4355, 35)
 {
  Outlier(1);
 };
};
Sequence()
{
 Boundary("Start Hienheim");
 Phase("Hienheim")
```

```
  {
   R_Date("GrN-5732", 4220, 55)
   {
    Outlier(1);
   };
   R_Date("GrN-6425", 4340, 40)
   {
    Outlier(1);
   };
   R_Date("GrN-7159", 3885, 40)
   {
    Outlier(1);
   };
   R_Date("GrN-7556", 4430, 45);
   R_Date("GrN-8689", 4305, 35)
   {
    Outlier(1);
   };
  };
  Boundary("End Hienheim");
 };
 Sequence()
 {
  Boundary("Start Hinterer Berg");
  Phase("Hinterer Berg")
  {
   R_Date("Erl-4775", 4241, 33);
   R_Date("Erl-4776", 4205, 53);
   R_Date("Erl-4777", 4224, 54);
   //inaccurate measurement based on assessment of collagen yield Erl-4778, 3217, 53
   R_Date("Erl-4779", 4142, 51);
   R_Date("Erl-4780", 4183, 50);
   //inaccurate measurement based on assessment of collagen yield Erl-4781 3821, 48
   R_Date("Erl-4782", 4254, 51);
  };
  Boundary("End Hinterer Berg");
 };
 Sequence()
 {
  Boundary("Start Kopfham, Galgenberg");
  Phase("Kopfham, Galgenberg")
  {
   R_Date("UB-2551", 4285, 85)
   {
    Outlier(1);
   };
   R_Date("GrN-12561", 4255, 40)
   {
    Outlier(1);
   };
```

```
  R_Date("GrN-12562", 4290, 45)
  {
   Outlier(1);
  };
  R_Date("GrN-12563", 4150, 60)
  {
   Outlier(1);
  };
  R_Date("GrN-12564", 4210, 60)
  {
   Outlier(1);
  };
  R_Date("GrN-12699", 4510, 30)
  {
   Outlier(1);
  };
  R_Date("GrN-12700", 4225, 30)
  {
   Outlier(1);
  };
  R_Date("GrN-12701", 4280, 35)
  {
   Outlier(1);
  };
  R_Date("GrN-12702", 4385, 35)
  {
   Outlier(1);
  };
  R_Date("GrN-14426", 4420, 35)
  {
   Outlier(1);
  };
  R_Date("GrN-14427", 4245, 50)
  {
   Outlier(1);
  };
  R_Date("GrN-14428", 4500, 80)
  {
   Outlier(1);
  };
  R_Date("GrN-14429", 4310, 60)
  {
   Outlier(1);
  };
 };
 Boundary("End Kopfham, Galgenberg");
};
Phase("Moosham")
{
 R_Date("Hd-8113", 4180, 65)
```

```
  {
   Outlier(1);
  };
  R_Date("Hd-8114", 4230, 60)
  {
   Outlier(1);
  };
  //not accurate measurements based on the ages Hd-8112-8173, 2835, 35 Hd-8115-8186, 5500, 60 Hd-8116-818, 6110, 55 Hd-8117-8193, 5810, 35
 };
 Phase("Oberschneiding")
 {
  R_Date("H-7442", 4350, 40)
  {
   Outlier(1);
  };
  R_Date("H-7443", 4170, 70)
  {
   Outlier(1);
  };
 };
 Sequence()
 {
  Boundary("Start Piesenkofen");
  Phase("Piesenkofen")
  {
   R_Date("Erl-17934", 4022, 48);
   R_Date("Erl-17935", 4414, 47);
   R_Date("Erl-17936", 4342, 48);
   R_Date("Erl-17937", 4343, 48);
   R_Date("Erl-17938", 4230, 49);
   R_Date("Erl-17941", 4483, 49);
   R_Date("Erl-17942", 4142, 48);
  };
  Boundary("End Piesenkofen");
 };
 Sequence()
 {
  Boundary("Rielding_Start_Cham_pottery")
  {
   color="Magenta";
  };
  Phase("Rielding Cham")
  {
   R_Date("BRAMS-3703", 4383, 30)
   {
    color="Magenta";
   };
   R_Date("BRAMS-3702", 4394, 22)
   {
```

```
     color="Magenta";
    };
    R_Date("BRAMS-4382", 4366, 22)
    {
     color="Magenta";
    };
    R_Date("BRAMS-4383", 4398, 22)
    {
     color="Magenta";
    };
    // intrusive or later activity Poz-115693, 4120 , 40
    // mixed deposit with MH pottery Poz-115527, 4385, 35 Poz-115528, 4390, 30
    First("first_Cham")
    {
     color="Magenta";
    };
    Last("last_Cham")
    {
     color="Magenta";
    };
    Span("duration_Cham_pottery");
   };
   Boundary("Rielding_End_Cham_pottery")
   {
    color="Magenta";
   };
  };
  Phase("Riekofen, Kellnerfeld")
  {
   //inconsistent results quoted not included in the model H-7409, 4252, 35 H-7411, 4307, 45 H-7412, 4327, 35
   R_Date("H-7410", 4692, 30)
   {
    Outlier(1);
   };
  };
  Phase("Wischlburg")
  {
   R_Date("KIA-21412", 4225, 46);
   R_Date("KIA-21413", 4378, 37);
  };
 };
 Boundary("End_Cham");
};
};
```