Converging Computational Evidence against an East-Germanic Clade

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Background

- The phylogeny of Germanic languages has been endlessly debated (see overviews in Rubekeil 2017; Stiles 2013:5–15; Grønvik 1998:67–82; Nielsen 1989:67–107).
- The bulk of debates have centered around the earlier regions of the Germanic tree and, recently, whether the East Germanic languages form a clade.
- A number of niche hypotheses about the diversification of Germanic languages are not considered further in this talk:
    - Did Proto-Germanic split into a clade consisting of Old High German and Gothic and another consisting of the Scandinavian languages (Rask 1818:63–72)?
    - Are Old Norse and Old English sisters (Bremer 1904:809-816, 842; Neckel 1927:11)?
    - Did Proto-Germanic originally split into Scandinavian (/North) and Continental (/South) followed by intense contact (Schirmunski 1965:34–5)?

Background

East and Northwest Gemanic (Lass 1998:169; Prokosch 1935:106)?

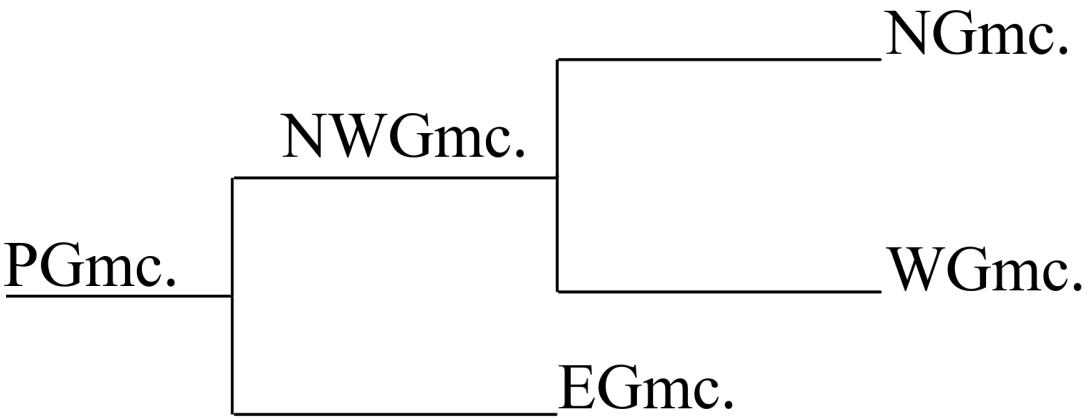


Fig. 1: Cladogram of the higher-order subgrouping of the Germanic languages

Background

Northeast “Gotonordisch” and West Germanic (Schwarz 1951:47–153; critiques in Stiles 2013:7; Nielsen 1989:87; Kuhn 1955:8)?

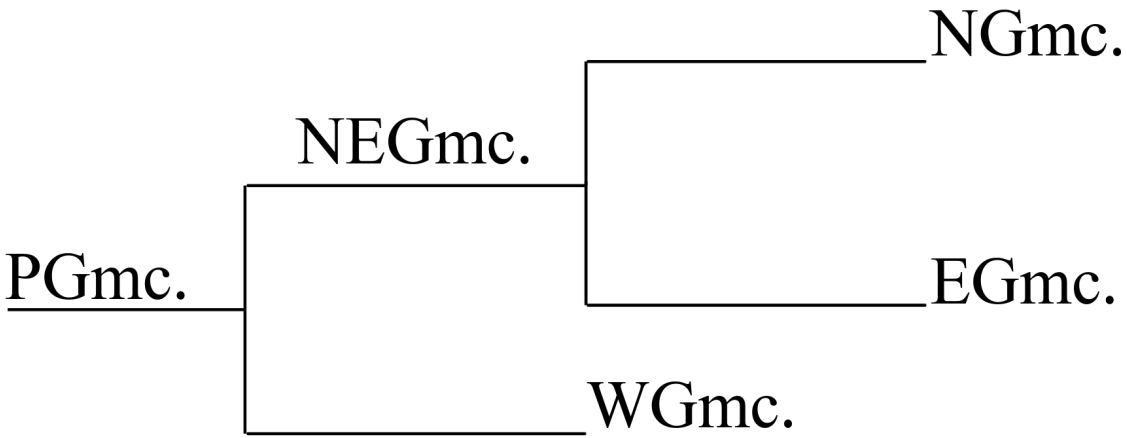


Fig. 2: Cladogram of the higher-order subgrouping of the Germanic languages

Background

East Germanic dialect continuum/rim vs. Northwest Germanic (Kim 2024; Hartmann 2024:189–92; Hartmann and Riegger 2022 contra Ruby 2025)?

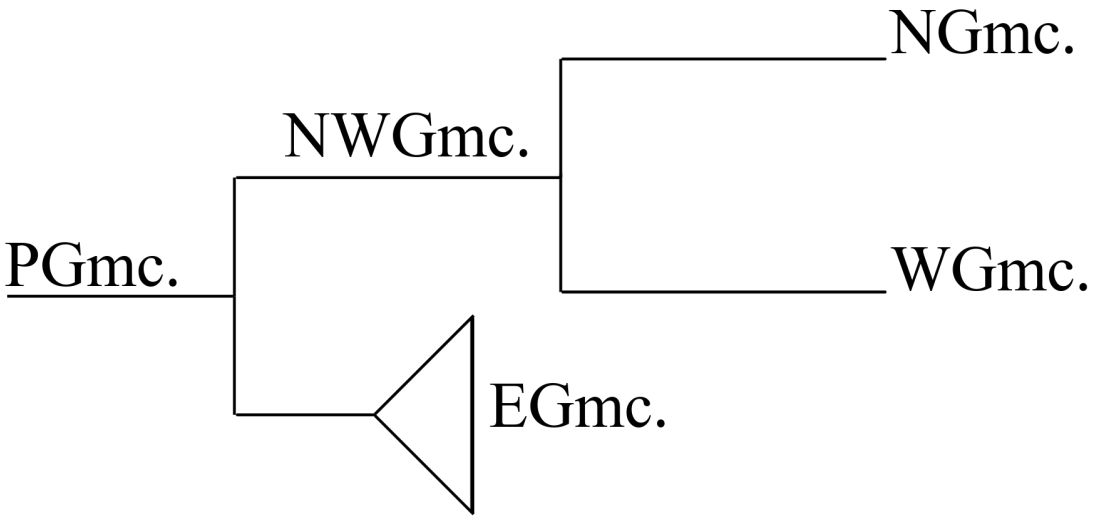


Fig. 3: Cladogram of higher-order subgrouping of Germanic languages

This talk

- Offers a comparison of tree topologies inferred using character-based methods.
  - Hartmann (2023) only employs distance-based non-Bayesian methods of tree inference which have several undesirable characteristics (cf. Goldstein 2020:41, 45).
- Discusses character support for various configurations of Gothic, Burgundian, and Vandalic.
- Provides a synthesis of some unique challenges in the phylogenetic modeling of the early Germanic languages.

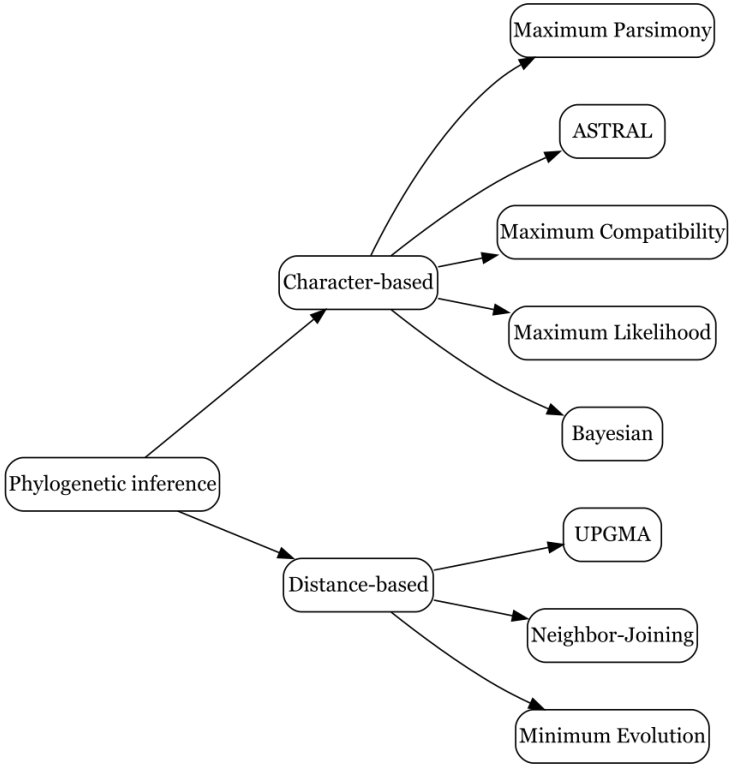


Fig. 5: Methods of Phylogenetic Inference (Zou et al. 2024:3–8; Felsenstein 2004:73–175, 248–304)

Roadmap

- Data
- Methods
- Results
- Discussion

DATA

Data

- The dataset records innovations and archaisms in the Germanic languages[1]
- Original dataset by Agee (2018) used in Agee (2021)
- Modifications to the dataset + the addition of Burgundian and Vandalic by Hartmann (2023)
- Modifications to the dataset based on Kim (2024)
- The dataset comprises 457 phonological, morphological, and morphosyntactic characters
- The fragmentary nature of the Burgundian and Vandalic corpora does not permit the use of lexical characters
    - Words for 4/161 meaning concepts from the IE-CoR and Leipzig-Jakarta list (cf. Anderson et al. 2025), attested in Vandalic
    - Pragmatically and semantically neutral default words (Heggarty 2021) or accidents of attestation?

1. These are called *derived conditions* in the biological literature and present unique modeling challenges.

Data encoding

Name	GO	ON	OE	OF	OS	OHG	VAND	BURG
*i, *u > [ɛ, ɔ] / _ <r, h, h^{w}>	1	0	0	0	0	0	0	0
*ai > $\bar{e}$	1	1	1	1	1	1	1	0
*z, *r > *r	0	1	1	1	1	1	0	0

Table 1: Innovations and archaisms in the Germanic languages

Data encoding

Character ID	Name	Type	PROTO	GO	ON	OE	OF	OS	OHG	VAND	BURG
M5	V2 in MC	Stand.	?	0	1	0	0	1	1	?	?
P6	*$ai > \bar{e}$	Irrev.	0	1	1	1	1	1	1	1	0
P39	*z, *$r > *r$	Irrev.	0	0	1	1	1	1	1	0	0

Table 2: Innovations and archaisms in the Germanic languages with character reversibility marked

- Unlike Hartmann (2023) and Agee (2021), we code all of the characters for reversibility and include it as a modeling component.

Data encoding

Character ID	Name	Type	PROTO	GO	ON	OE	OF	OS	OHG	VAND	BURG
M5	V2 in MC	Stand.	?	0	1	0	0	1	1	?	?
P6	*$ai > \bar{e}$	Irrev.	0	1	1	1	1	1	1	1	0
P39	*z, *$r > *r$	Irrev.	0	0	1	1	1	1	1	0	0

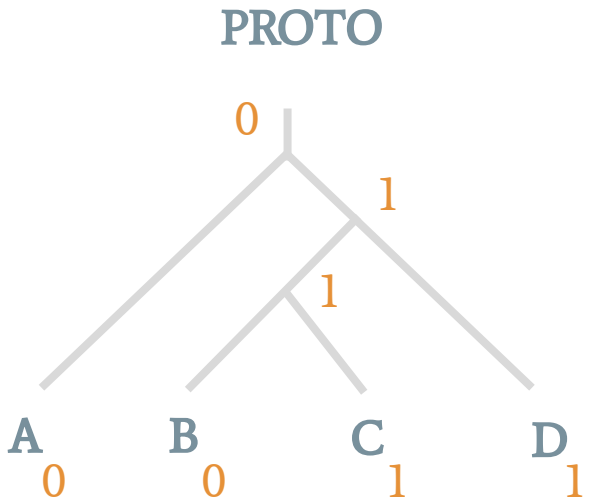
Table 2: Innovations and archaisms in the Germanic languages with character reversibility marked

- Mergers and sound changes where the conditioning environment lost encoded as irreversible (cf. Garde 1961, Labov 2010:121–39).
- Changes for which reversals attested/frequent coded as standard (e.g., the loss of V2 [cf. Wolfe 2024, van Kemenade 2012]).

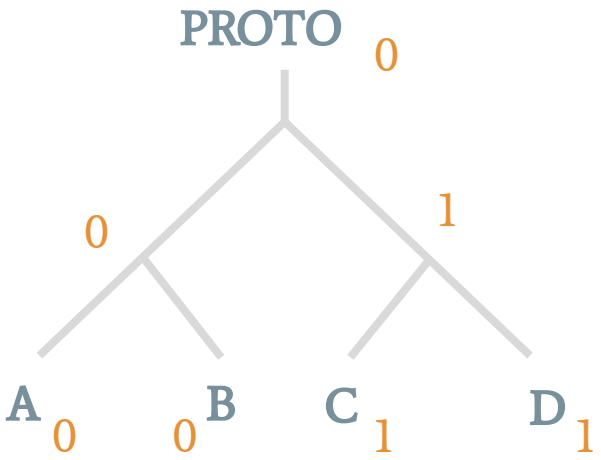
METHODS

Maximum Parsimony (Swofford 1997)

Type	PROTO	A	B	C	D
Stand.	0	0	0	1	1



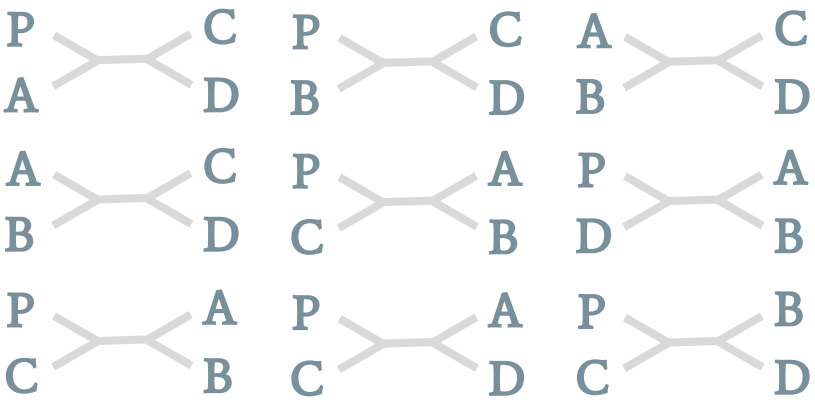
2 changes: not maximally parsimonious

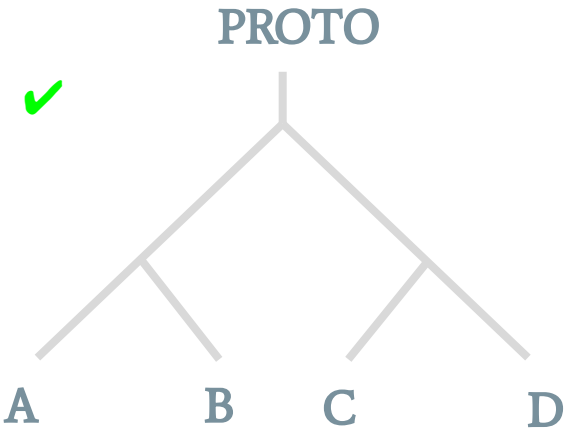


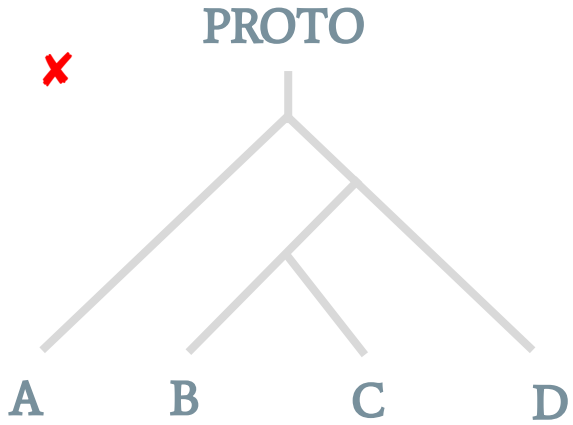
1 change: maximally parsimonious

ASTRAL (Zhang et al. 2018)

PROTO	A	B	C	D
0	0	0	1	1
0	1	1	0	0
0	1	1	0	1

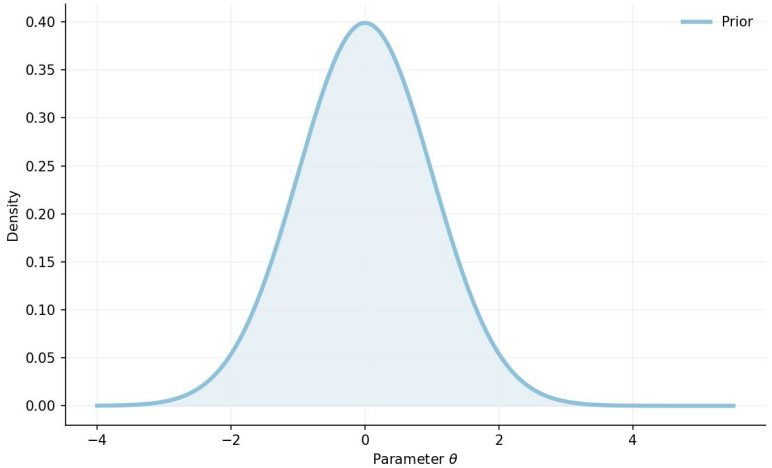






Bayesian phylogenetics

Bayesian phylogenetic methods combine **prior expectations** about evolutionary trees and their parameters with the **likelihood of trees** and parameters given the data to produce a **posterior probability distribution** over trees and parameters rather than a single **point estimate.**



Prior expectation over trees

Bayesian phylogenetics

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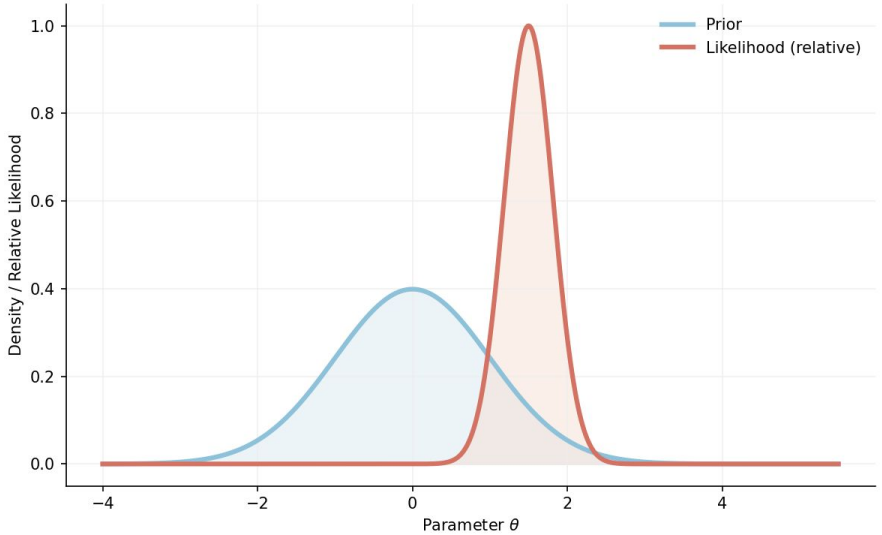
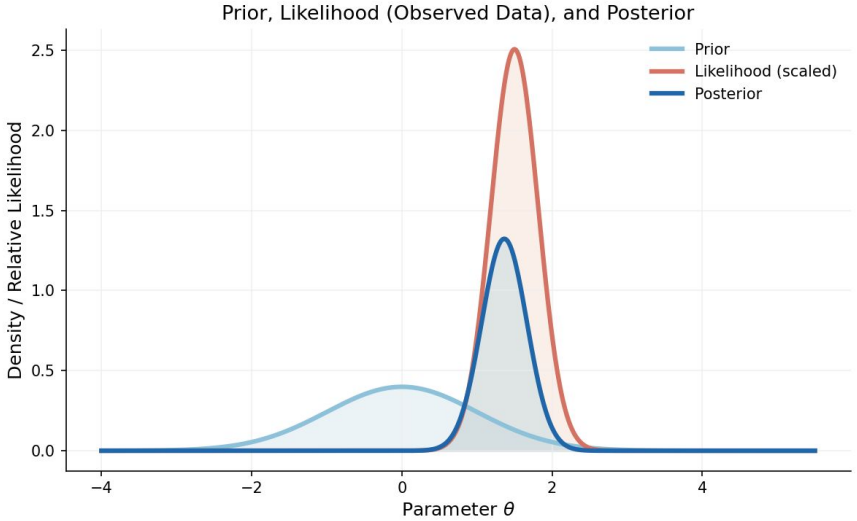


Prior * Likely values of trees given observed data

Bayesian phylogenetics

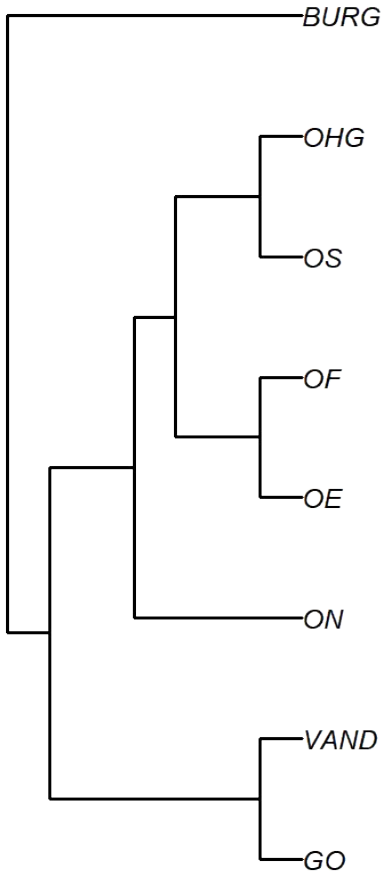
Bayesian phylogenetic methods combine **prior expectations** about evolutionary trees and their parameters with the **likelihood of trees** and parameters given the data to produce a **posterior probability distribution** over trees and parameters rather than a single **point estimate.**



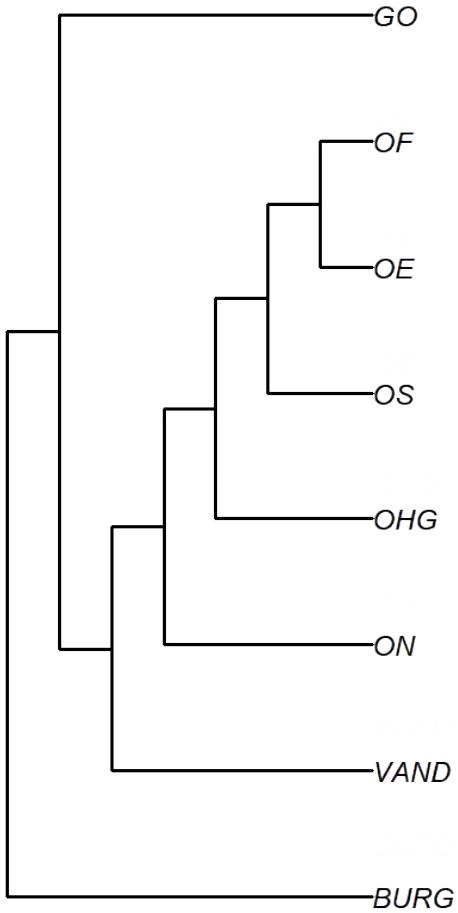
Posterior $\propto$ Prior * Likelihood

RESULTS

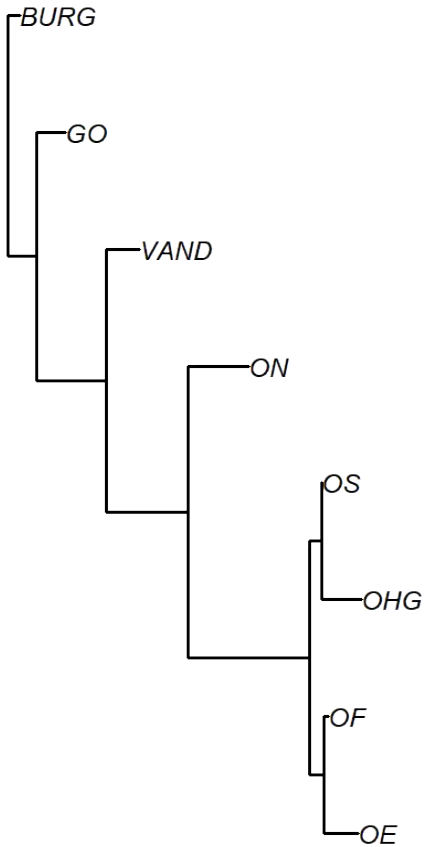
Maximum Parsimony



ASTRAL-EVANS-ALL

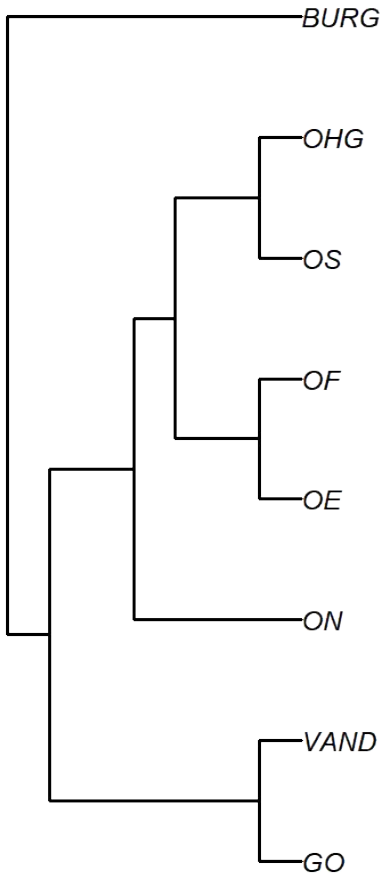


Bayesian MCC Tree
(MK/GTR2-Strict-Exp)



Results

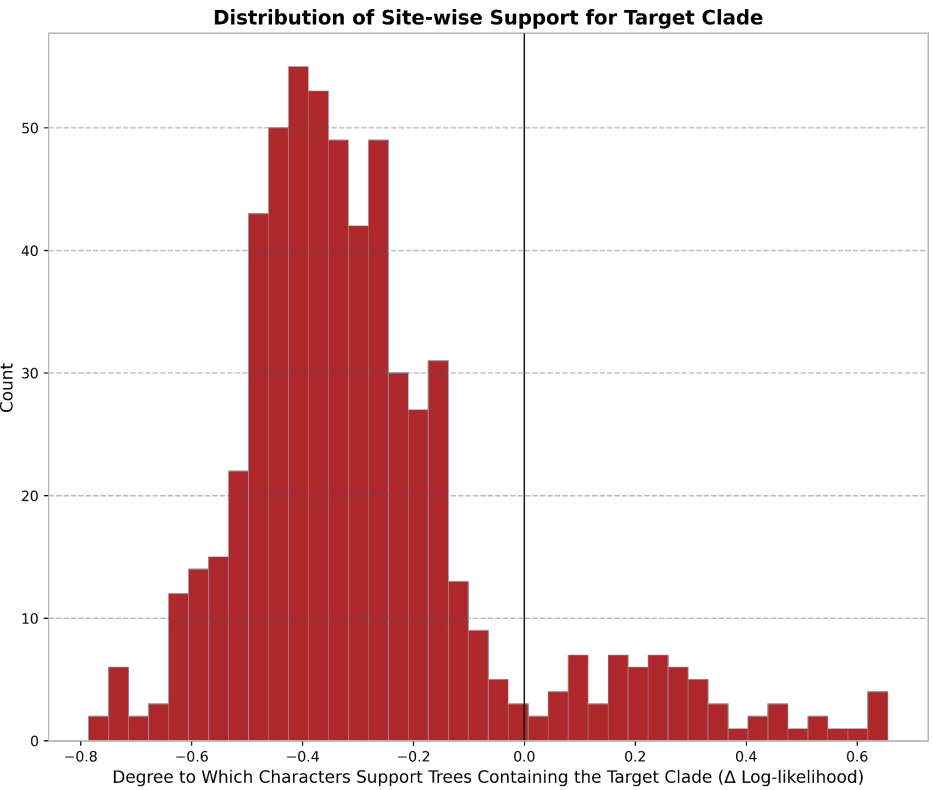
- None of the Bayesian posterior tree samples return an East Germanic clade.
- All of the methods agree in having Burgundian as the first to split off.
- Bayesian and ASTRAL trees agree in treating Gothic as the second language to branch off from Proto-Germanic.
- Maximum Parsimony, however, returns a Gotho-Vandalic clade.
- Gotho-Vandalic has been proposed in the literature (see Reichert 2009) but Vandalic lacks the general raising of **e* > **i* (Hartmann 2020: 114–5) and Holtzmann's law (101).



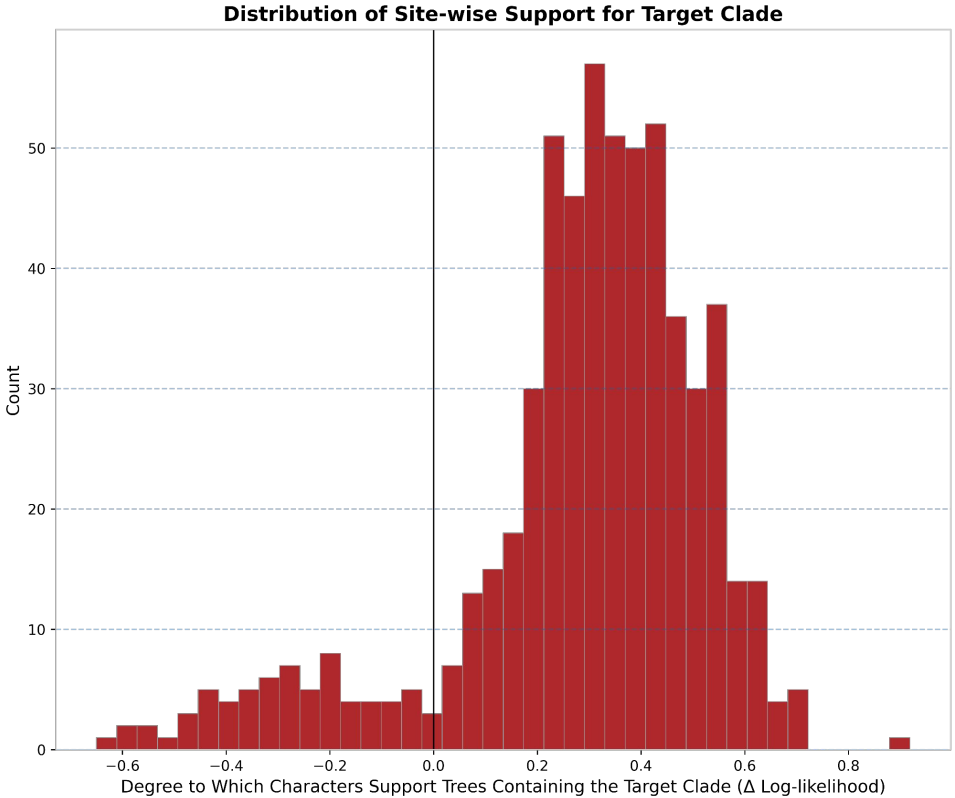
Maximum Parsimony

DISCUSSION

Hypothetical site support in Bayesian analyses

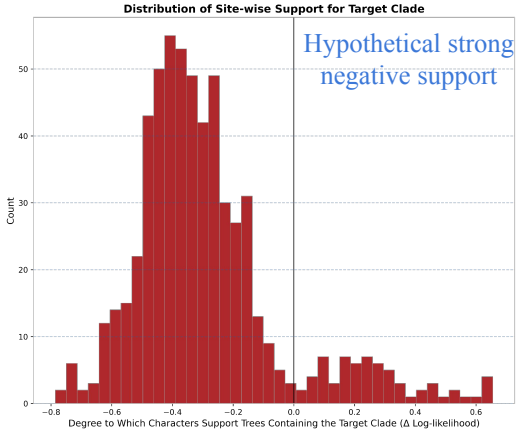


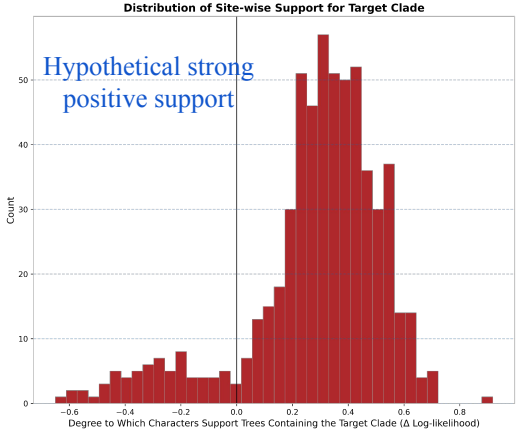
Hypothetical strong negative support

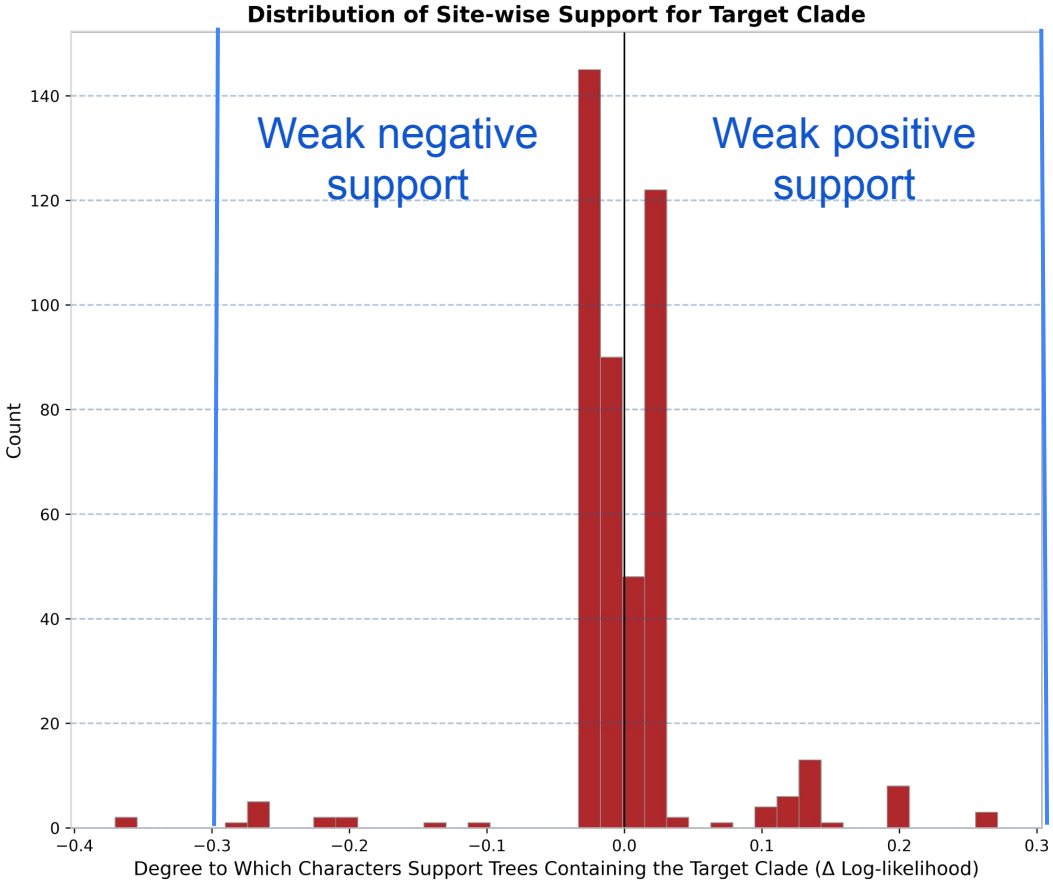


Hypothetical strong positive support

Site-wise support for Gotho-Vandalic (Bayesian posterior tree samples)

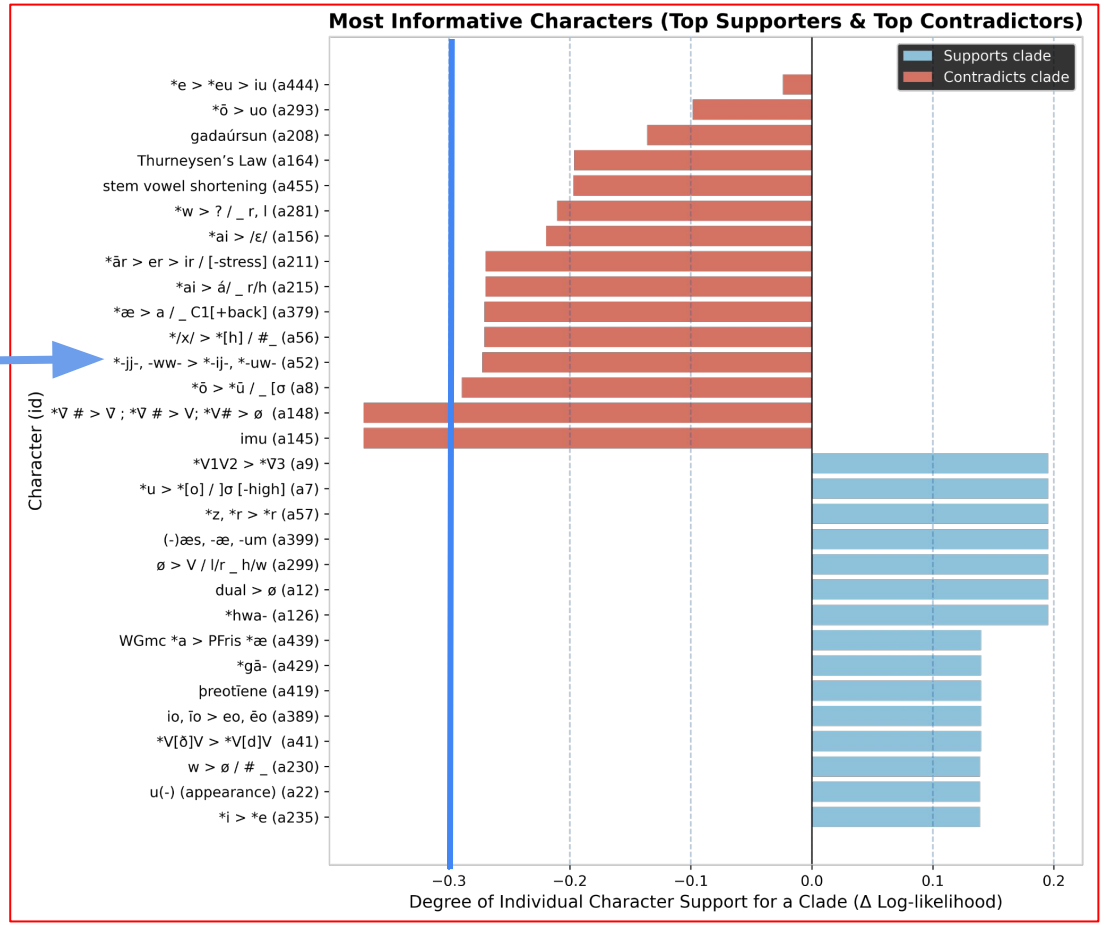






Character support for a Gotho-Vandalic clade (Bayesian posterior tree samples)

- Divergent treatment of geminate glide clusters:
  - Holtzmann's Law (aka Verschärfung) in Old Norse and Gothic
  - Glide vocalization in Vandalic



How many characters support a Gotho-Vandalic clade?

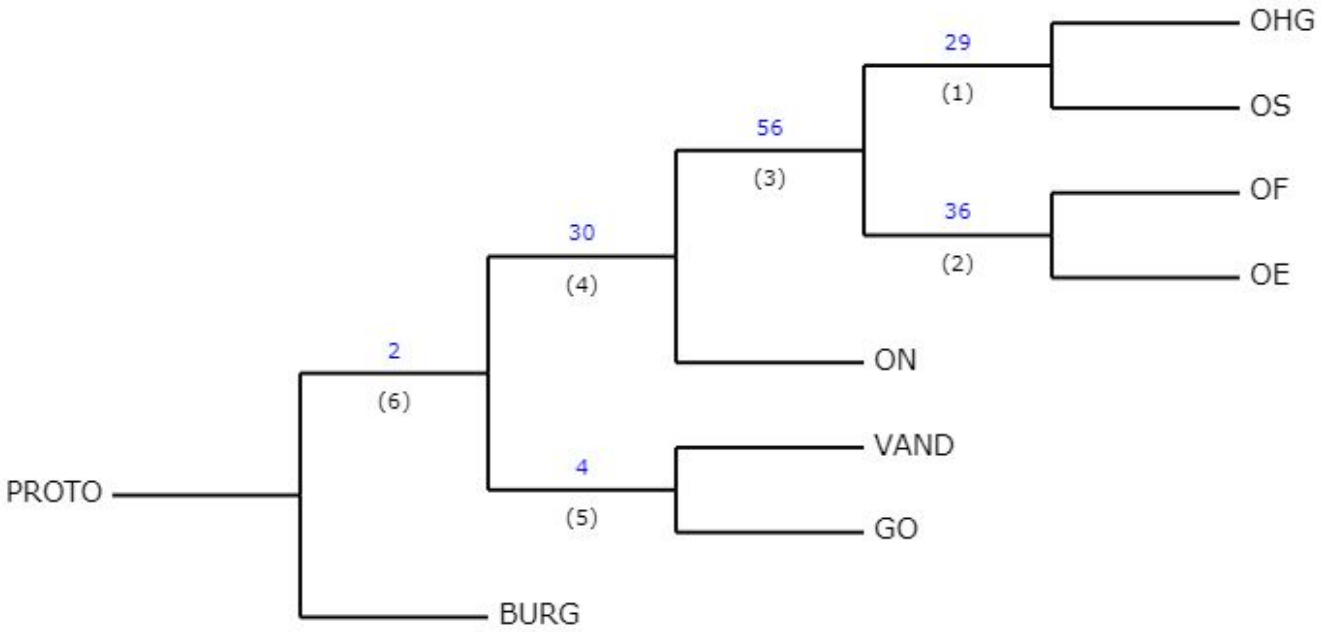


Fig. 6: MP Character support for Germanic subgroups (visualized with LinguiPhyR [Canby 2024])

Which characters support a Gotho-Vandalic clade?

***#*h* (/x/) > #/h/: Word-initial debuccalization of the PGmc. voiceless velar fricative (cf. Kim 2024:32)**

- Surely there must have been inter- and intra-speaker variation in the articulation of the voiceless velar fricative /x/ in PGmc. (Ronald Kim, p.c.).
- The debuccalization in Vandalic and Gothic could have easily been an independent or parallel innovation.
- Both scenarios would find typological support.
    - **Parallel innovation Scenario**:
        - Lavoie (1996) finds that velar fricatives and original velar stops debuccalize to glottal fricatives very frequently (290–1).
    - **Diffusion Scenario**:
        - Parallel in the realization of the voiceless velar fricative in Eastern Andalusian Spanish: [h] ~ [x] ~ [ɦ] (Haro and Hajek 2022:143).

Which characters support the Gotho-Vandalic clade?

***#*h* (/x/) > #/h/: Word-initial debuccalization of the PGmc. voiceless velar fricative (cf. Kim 2024:32)**

- **Phonetic differentiation Scenario**:
  - Yet another scenario would be to treat the word-initial reflexes of PGmc. **h* /x/ as having distinct phonetic outcomes in Vandalic and Gothic.
  - The reflex of PGmc. **h* /x/ is written with <h>, <ʿ> and sometimes <ch>, <g>, <χ>.
    - According to Hartmann (2020:73), such a practice could indicate a sound of higher perceptibility.
    - Hartmann's observation could suggest a pronunciation [χ].

Which characters support the Gotho-Vandalic clade?

- ***#*h* (/x/) > #/h/: Word-initial debuccalization of the PGmc. voiceless velar fricative (cf. Kim 2024:32)**
  - **PGmc. *#*h* (/x/) > # Vand. /χ/?**
    - Consistent with possible backing as a diachronic intermediate stage of lenition on the stage to debuccalization (Gildea 1995:84).
    - Consistent with robust evidence for higher perceptibility of uvular fricatives because of their resonant-like formant structure (see Rehan 2025 for discussion).
    - On the other hand, Gothic most likely had [h] word initially (Vennemann 1972:878, see discussion in Miller 2019:27).
  - The scenario outlined here would also provide support against a Gotho-Vandalic clade but parallel innovation and diffusion is not strictly possible to rule out.

The other characters supporting a Gotho-Vandalic clade

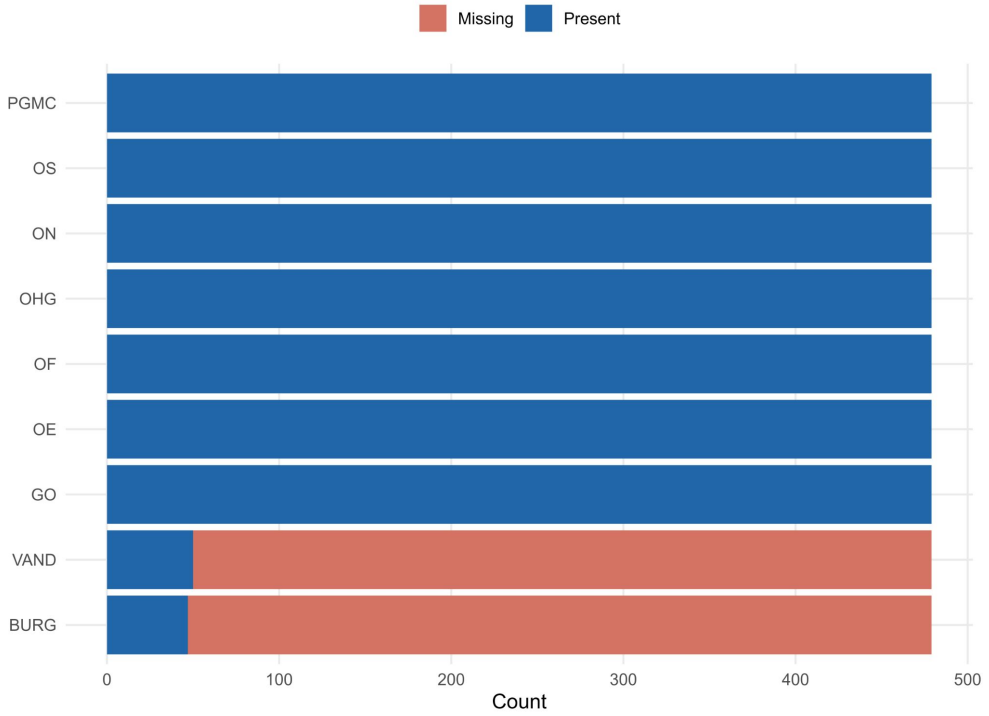
- **P73 **ai* > /ɛː/ ([e_{II}] in Hartmann's notation [2020:50–1])**
  - <ai>, <ei> reflect traditional writing of sounds in accordance with the Gothic Bible and an early stage of Vandalic.
- **P74 **au* > /ɔː/ ([o_{II}] in Hartmann's notation [2020:55])**
  - Monophthongization of PGmc. **ai* and **au* in Gothic (Braune and Heidermanns 2004: 38–46) was probably a recent change in Wulfila Bible translation (see Kim 2024: 29 n.22 for discussion and references).
  - Likewise, there is evidence that at least the monophthongization of **au* > /ɔː/ was late in Vandalic (Hartmann 2020:52–5).
  - Again, hard to rule out parallel innovation: cf. Kim argues that Crimean Gothic and Bible Gothic independently monophthongized **ai* > /ɛː/ and **au* > /ɔː/.

Morphological character supporting a Gotho-Vandalic clade in MP

- M88 -*a* < PGmc. *-*ō̃* from leveling in the *n*-stems (Ringe 2017:306–7)
  - cf. Ostrogothic *Tanca, Merila* (PNs)
  - “likely to be an archaism vis-à-vis OE -*a*, OHG -*o* < (post-)PGmc. *-*ǭ*.” (Kim 2024:34)
  - At least early Runic shows the same leveling in the same masc. nom sg. -*a*, so by no means a unique development.
- None of the characters conclusively support a Gotho-Vandalic clade inferred by MP.
- MP suffers from a well-known phenomenon called “long-branch attraction” in which two long branches accumulate parallel changes and are erroneously grouped together (Felsenstein 1978).

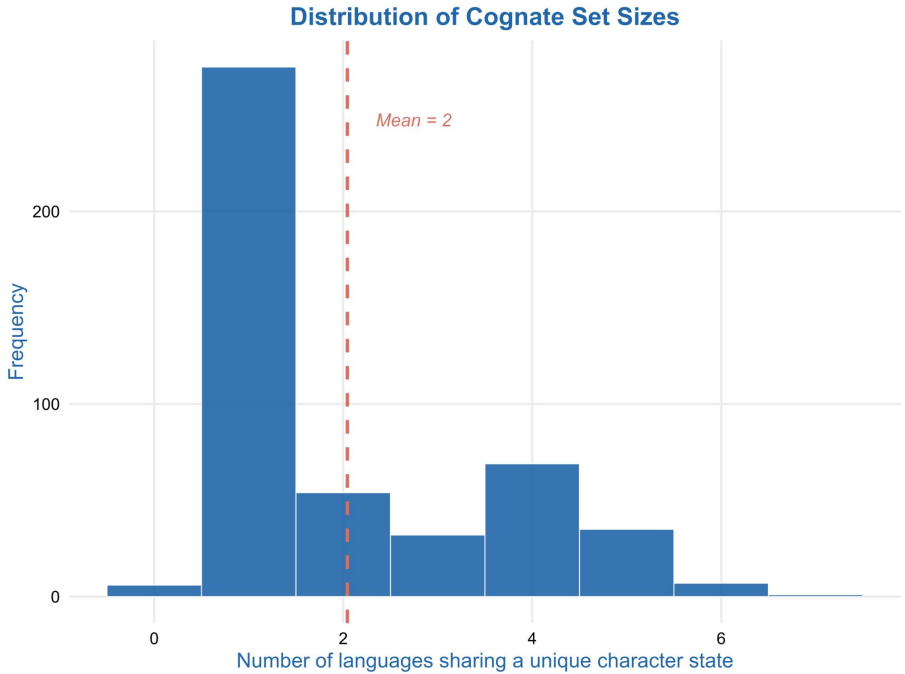
Missing data

- Ambiguous/Missing characters (“?”) reduce phylogenetic accuracy.
- Severity of inaccuracy governed by the distribution of ambiguous characters across taxa (see Lemnon et al. 2009:131 for references) among other factors.
    - Vandalic and Burgundian are missing all of the missing character states.
- Trees constructed on highly incompletely taxa (> 75% ambiguous sites) from character sets of equivalent size (~ low 100s) found to be inaccurate in simulation studies regardless of method (Wiens and Morrill 2011:720–1; Wiens 2006:36; Huelsenbeck 1991).

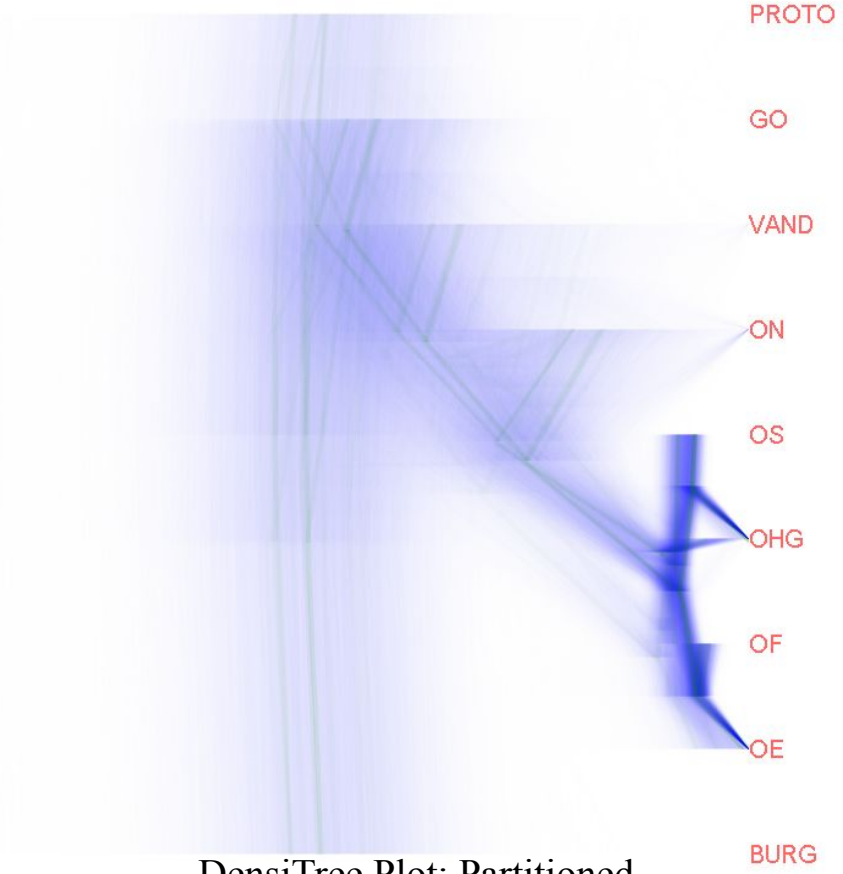


Lack of informative data

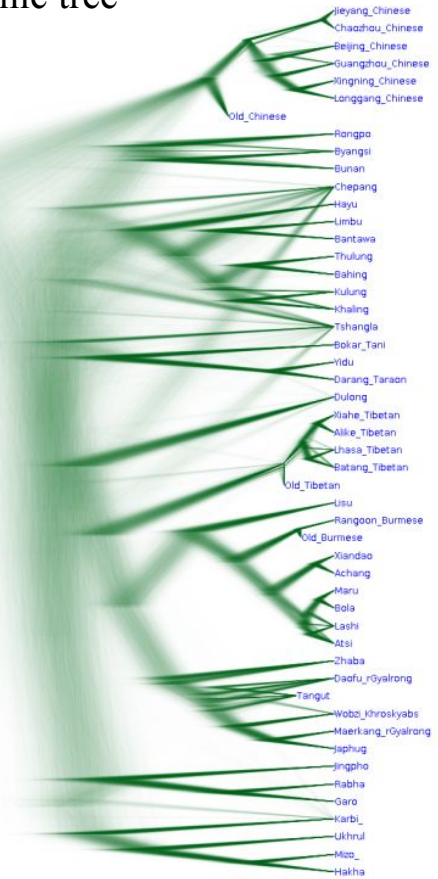
- The strength of topological support from unambiguous characters determines the bias resulting from ambiguous characters (Lemnon et al. 2009:141, Wiens 2003).
- Most characters do not provide any evidence for subgrouping.
- Maximum parsimony may be more sensitive than Bayesian analyses to the lack of overlap in character data between taxa (Wolsan and Sato 2010:183, Roure et al. 2013).



Posterior estimates reflect high uncertainty in the early regions of the Germanic tree



DensiTree Plot: Partitioned (MK/GTR2+STRICT+EXP)



Strict clock DensiTree Plot from Sagart et al's 2019 analysis of the Sino-Tibetan languages

Conclusions

- No evidence across multiple methods for an East Germanic clade (*contra* e.g., Krahe 1948:21–3, Ruby 2025).
- No evidence across multiple methods for Gotho-Burgundian or Gotho-Nordic (see appendix).
- Evidence for a Gotho-Vandalic clade is an artefact of the inference method and not corroborated by the Bayesian and ASTRAL analyses.
- Characters supporting a Gotho-Vandalic clade in Maximum Parsimony are most likely homoplasies, archaisms, or slightly different in details.
- The methodology to calculate site-wise posterior support for clades in Bayesian analyses can be applied to other datasets.
- Bayesian methods are more robust to missing data, but the results of these and previous analyses based on this dataset should be viewed with caution.

THANK YOU FOR LISTENING!
QUESTIONS? COMMENTS?[2]

2. We are very thankful to Ronald Kim, David Goldstein, Tandy Warnow, and to the members of the PIES Graduate Seminar for their help with various aspects of this presentation.

Trends in phylogenetic modeling

- Recent years have seen an exponential growth in the use of computational phylogenetic methods to infer the evolutionary history and dynamics of languages (Greenhill 2023, Greenhill et al. 2020, Bowern 2018).
- Each method carries with it assumptions and must be compared against alternative methods for robustness.
- These methods, along with careful curation of the data, can yield new insights into the evolution of the Germanic languages.

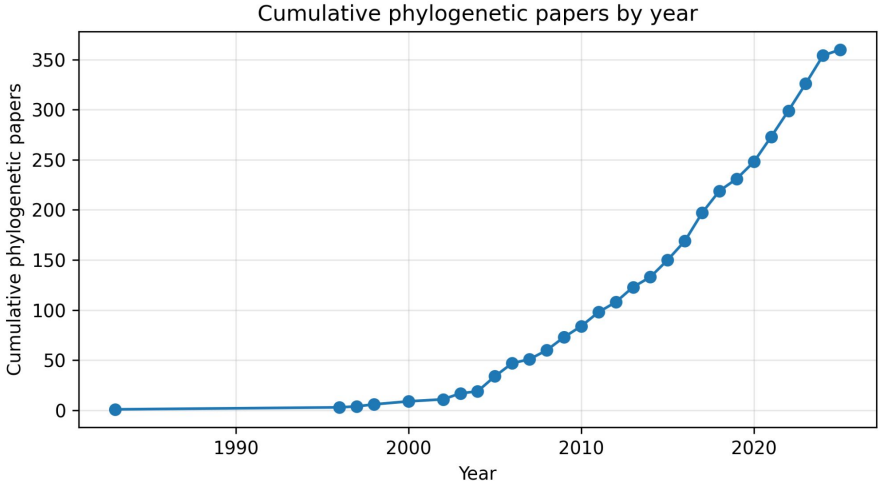
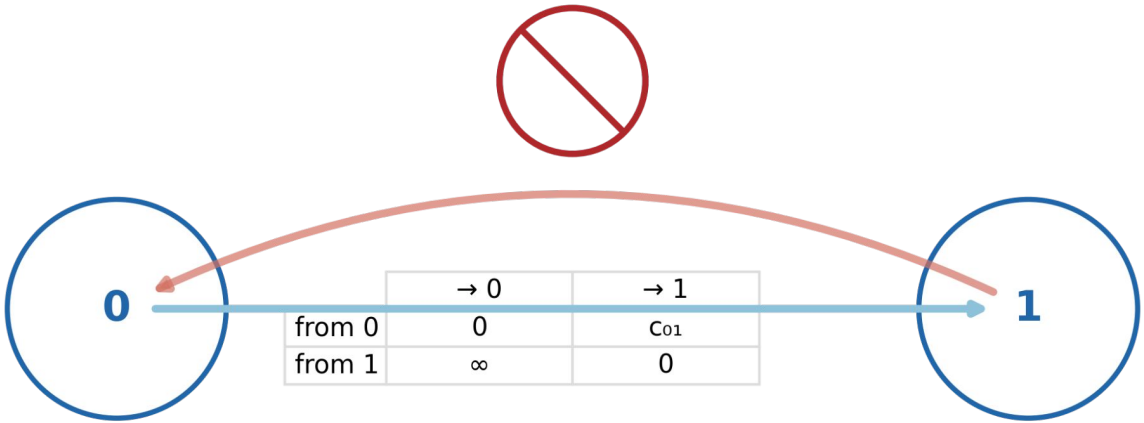


Fig. 4: Data from Greenhill 2023 + https://github.com/SimonGreenhill/langphydb

Treating Irreversible vs. Standard characters (MP)

- In Maximum Parsimony, an infinite cost is assigned for a transition to 0 for an irreversible character.
  - Camin and Sokal criterion (1965): Character evolution into an innovative state (derived condition) is irreversible.

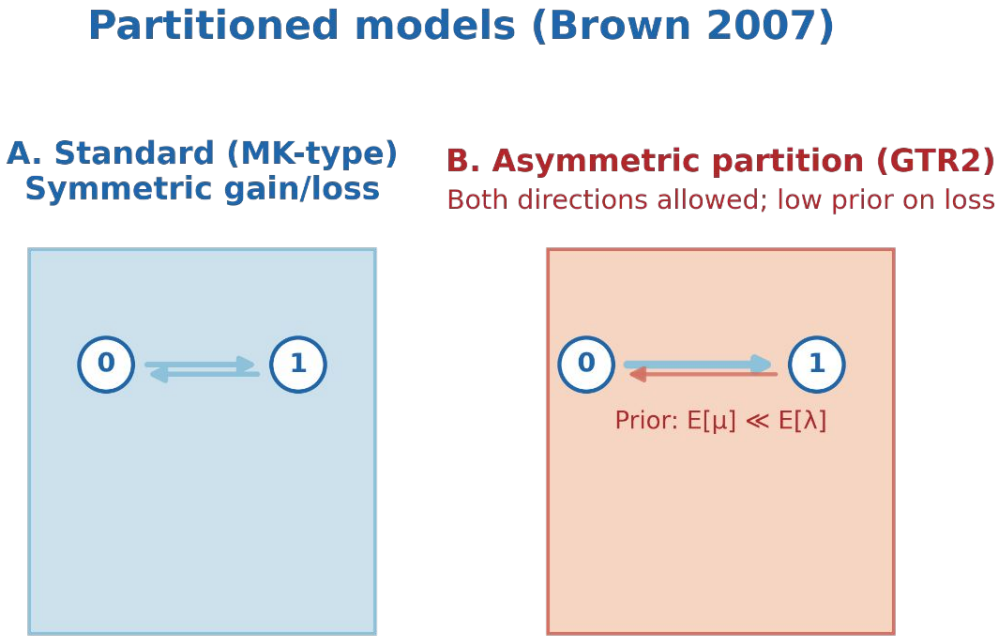


	→ 0	→ 1
from 0	0	c_{01}
from 1	∞	0

Weighted Maximum Parsimony Cost Matrix

Treating Irreversible vs. Standard Characters (Bayesian)

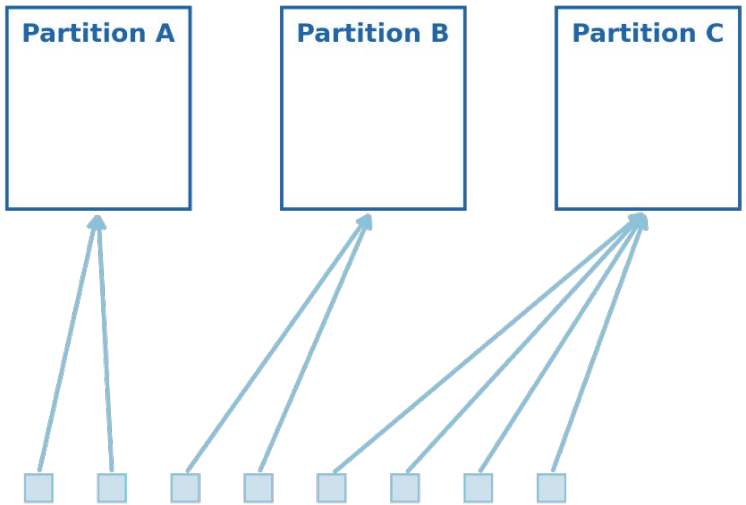
- Among the Bayesian phylogenetic models, two modeling alternatives are considered and evaluated against each other by model comparison (in RevBayes [Höhna et al. 2016]):



Treating Irreversible vs. Standard Characters (Bayesian: An Alternative Approach)

F-81 mixture model (Pagel & Meade 2004; Wright et al. 2016)

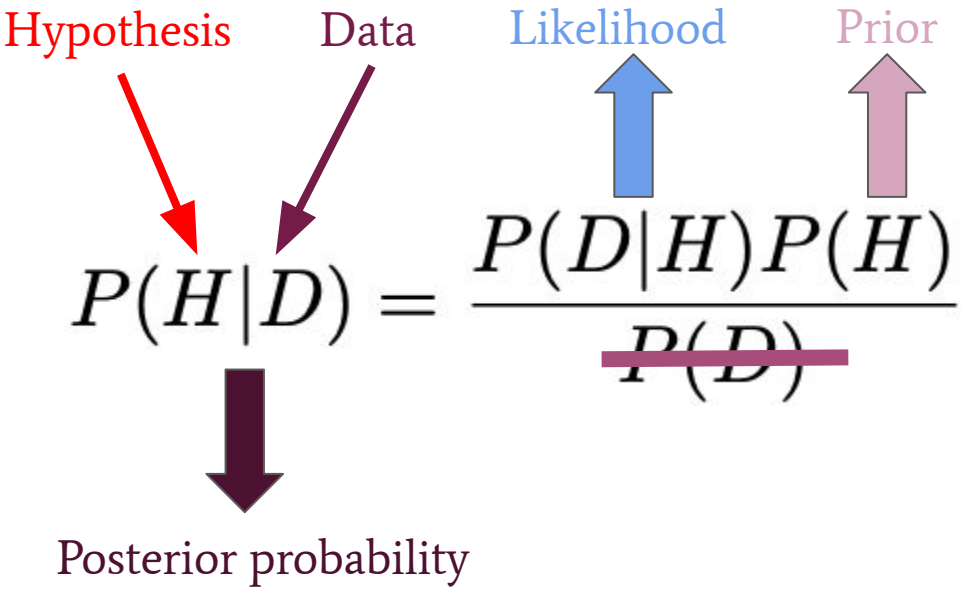
Asymmetric gain/loss for all characters; characters assigned to partitions to maximize total log-likelihood



Per-partition asymmetric rates (λ_i, μ_i) are estimated; assignment chosen to maximize total log-likelihood.

Bayesian phylogenetics

At the core of Bayesian phylogenetics is Bayes theorem (Goldstein Forth., McElreath 2020, Nascimento et al. 2020).



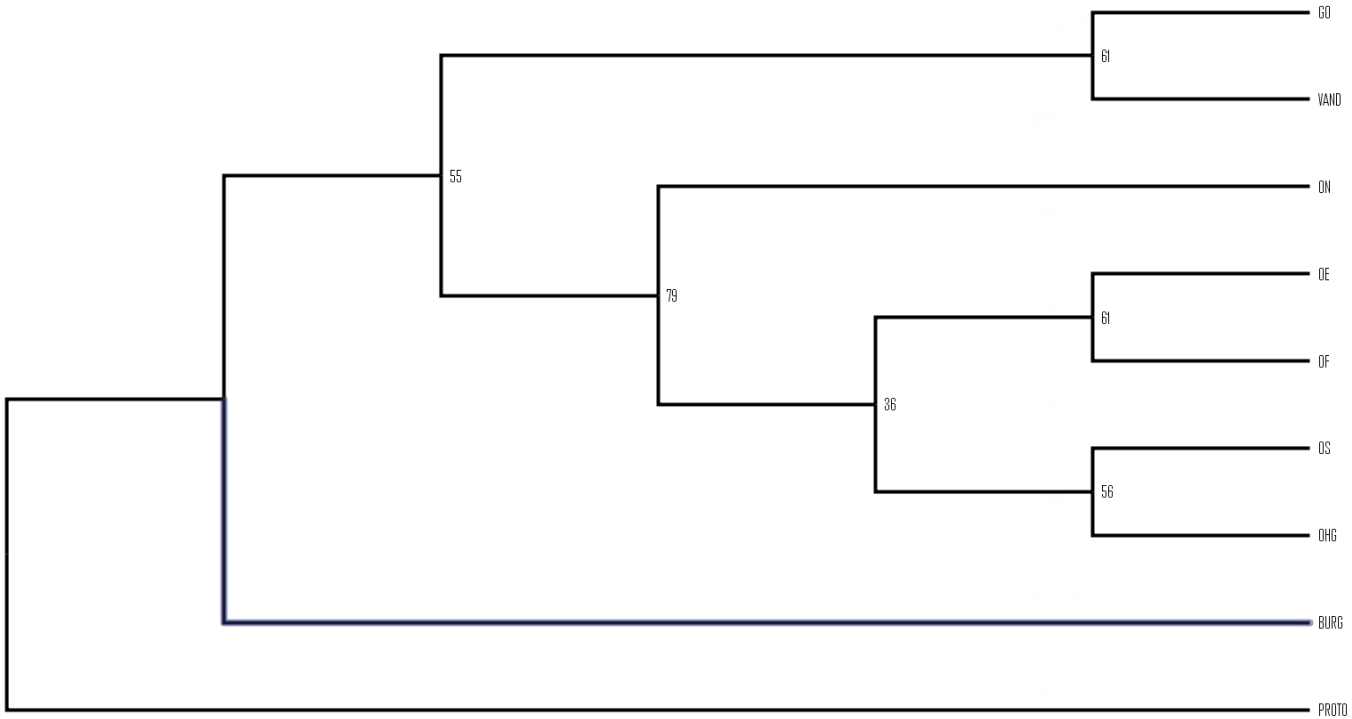
Defining the likelihood function of a Bayesian phylogenetic model

- Model of character evolution
  - How do characters evolve from one state into another (e.g., Stochastic Dollo [Nicholls & Gray 2008])?
- Rate heterogeneity among characters?
  - Do some characters evolve faster or slower than others? (Yang 1996)
- Clock model
  - How quickly does change happen?
  - Does it happen at the same rate in the entire tree (Drummond et al. 2006)?
- Tree prior
  - What is the shape and tempo of speciation and (extinction) events?

Bayesian Models

Modeling component	Partitioned	Unpartitioned
Instantaneous rate-matrix	MK (Standard) + GTR2 (Irreversible)	F-81 Mixture Model
Clock Models	Strict, UCLN, UCED	Strict, UCLN, UCED
Tree Prior	Yule	Yule
Branch Length	Exponential Prior	Exponential Prior
Rate heterogeneity	No rate heterogeneity	No rate heterogeneity

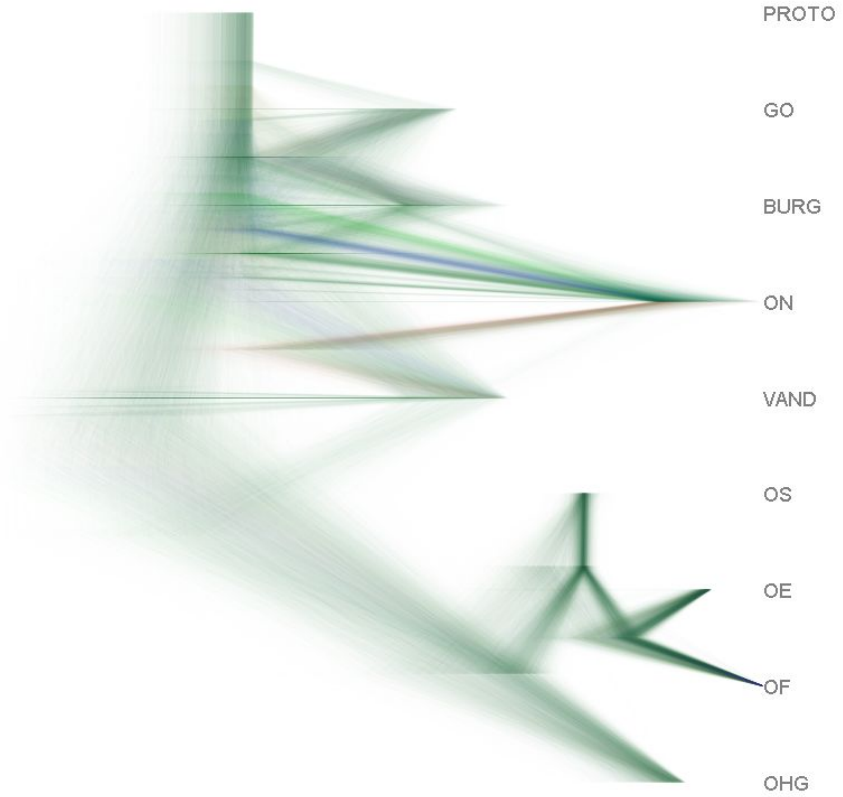
Maximum Likelihood Tree



Inferred using IQ-Tree (Wong et al. Forth)

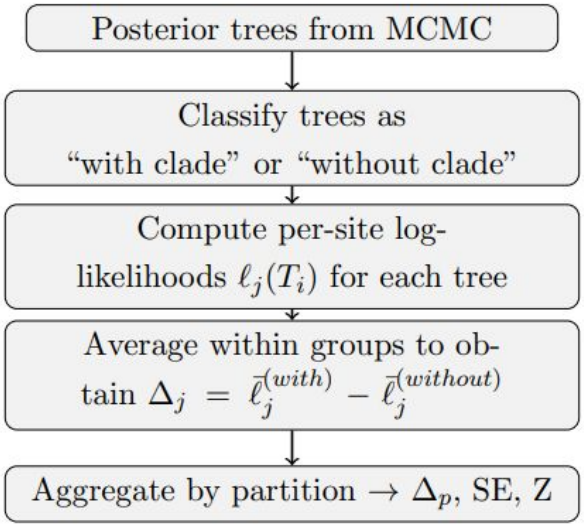
(iqtree3 -s all_standard.nex -st BIN -m GTR2+G4+F -B 1000 -alrt 1000)

Germanic MK+Strict+FBD DensiTree Plot



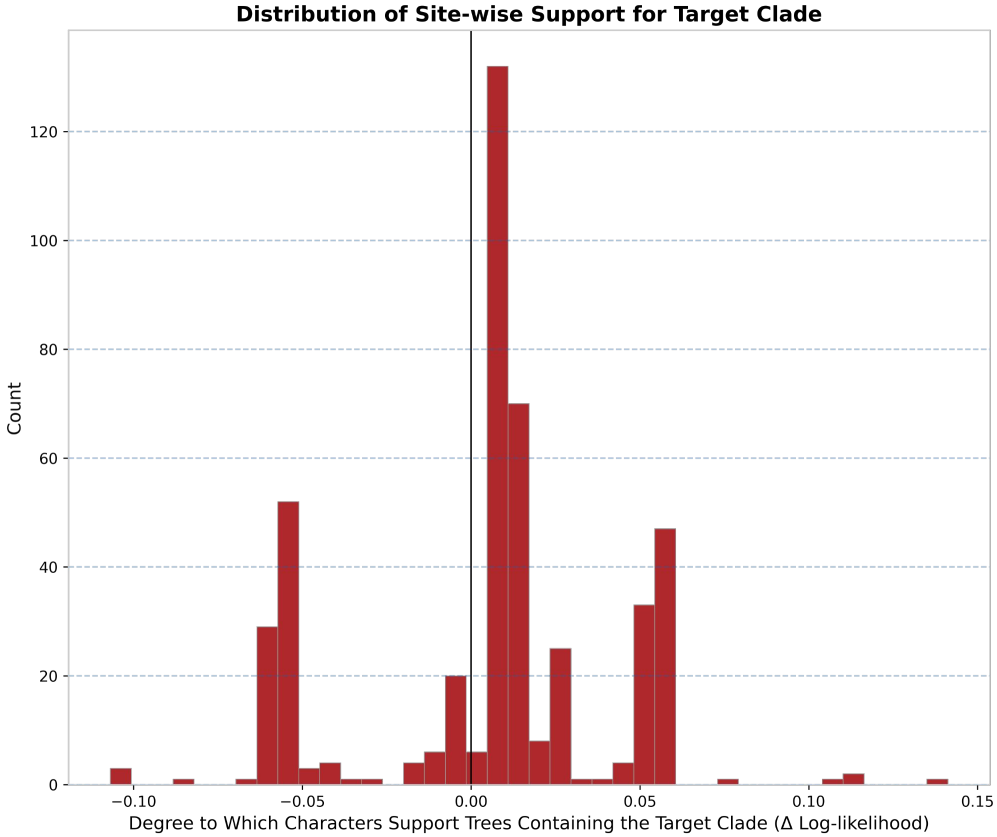
Language	Date Range
Gothic	1600–1800 BP
Old English	1100–1300 BP
Old Frisian	800–1000 BP
Old Saxon	1150–1350 BP
Old High German	1150–1350 BP
Old Norse	1000–1200 BP
Burgundian	1500–1700 BP
Vandalic	1500–1700 BP

Computing character support from Bayesian posterior samples

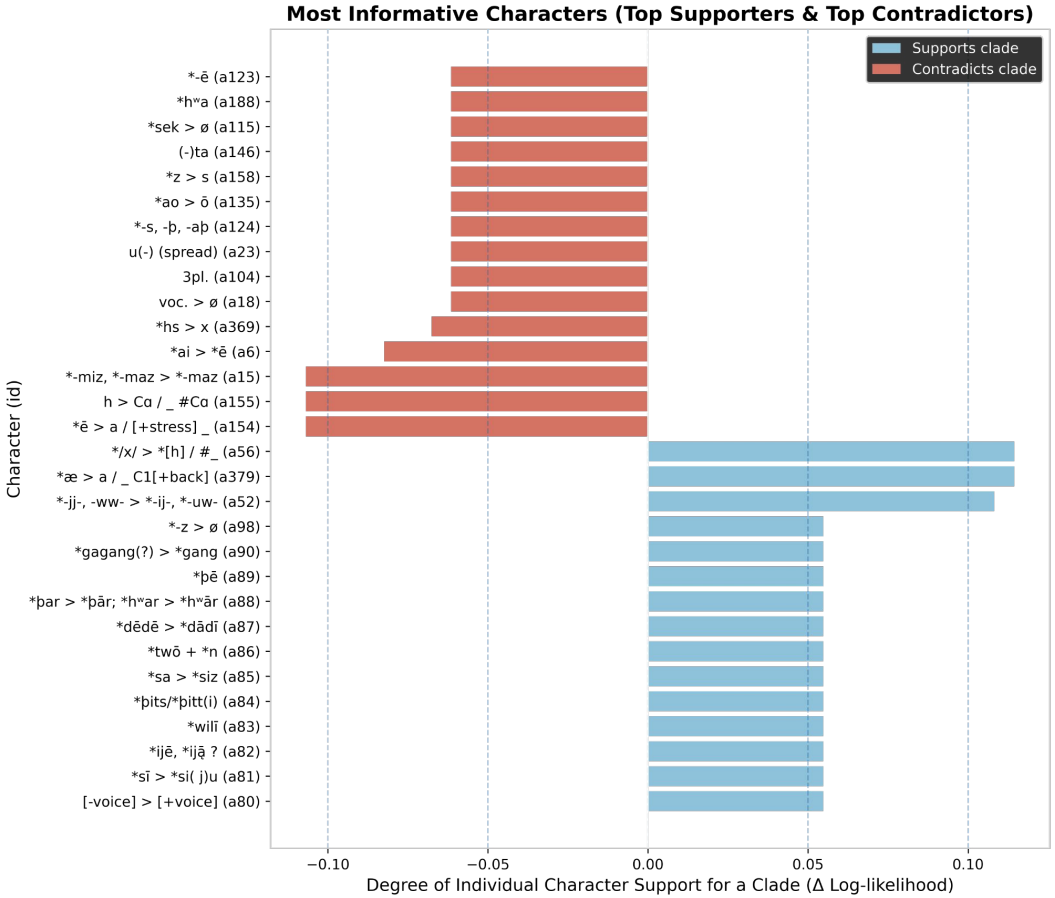


Interpretation. Positive Δ_j and Δ_p values indicate that the corresponding characters or partitions fit better on trees containing the clade; negative values indicate the opposite.

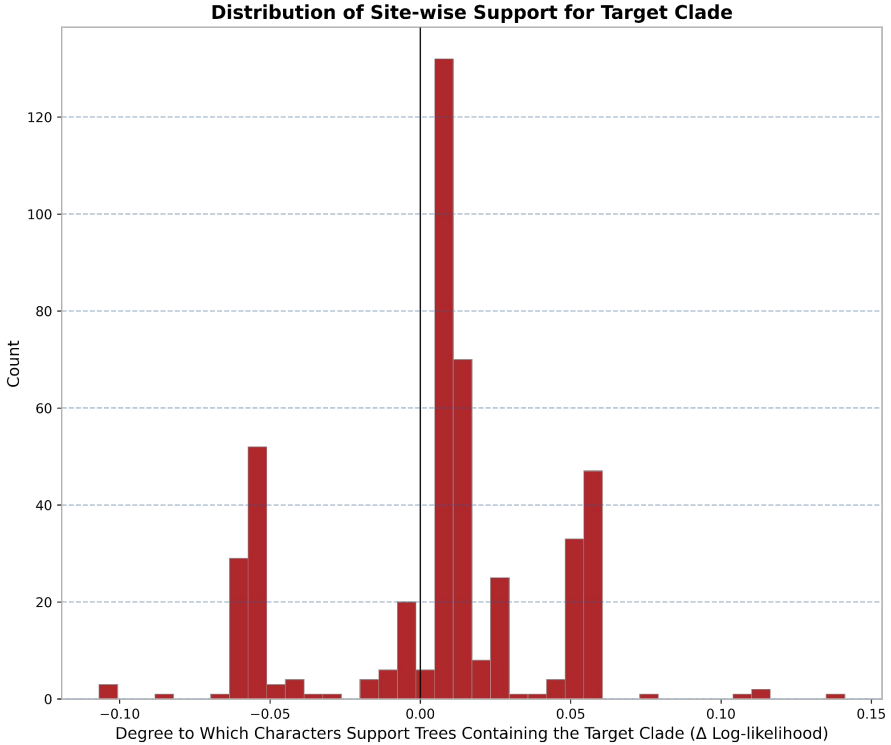
Site-wise support for a Gotho-Nordic clade from Bayesian posterior tree samples



Character support for a Gotho-Nordic clade from Bayesian posterior samples



Weak negative support for Burgundian being a sister to the MRCA of the other Germanic languages

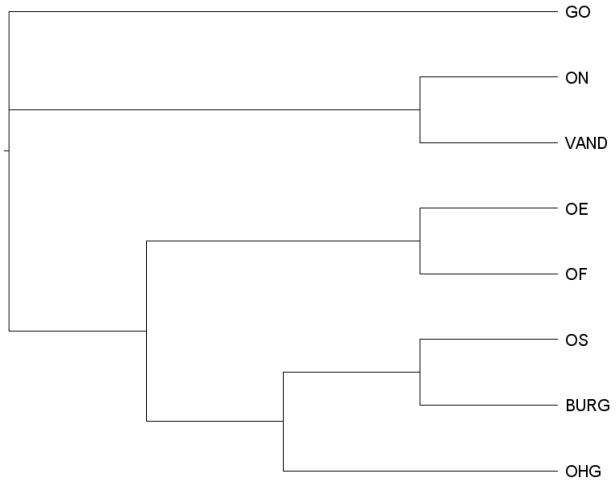


Slightly negative information theoretic support for BURG vs. rest of Germanic

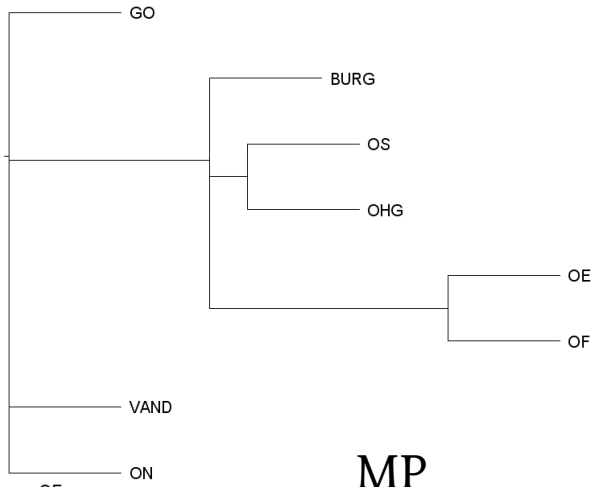
Morphological vs. Phonological characters

- Morphological characters generally thought by Indo-Europeanists to provide the most robust evidence for subgrouping (Ringe, Warnow, and Taylor 2002:65-70; Nakhleh, Ringe, and Warnow 2005:395–6; Clackson 2007:6; Kim 2024:23[5]).
- Yet, we have paltry evidence for morphological innovations in the early Germanic languages.
- The results of tree inference on just the morphological characters confirms the issue.
- Phonological characters unlikely to provide robust evidence for subgrouping unless phonetically unnatural or relative chronology can be established.

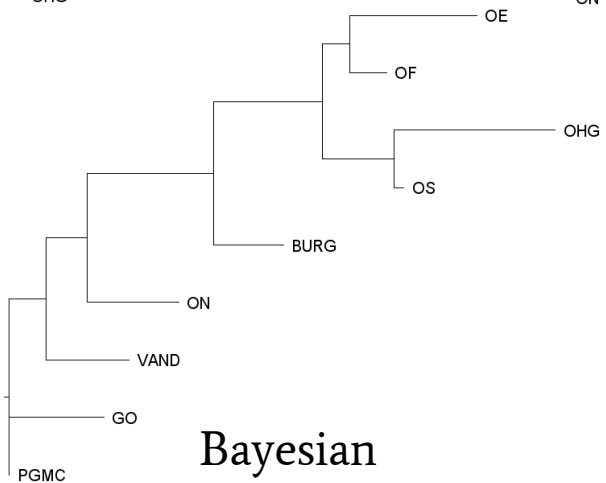
Trees inferred using only morphological characters



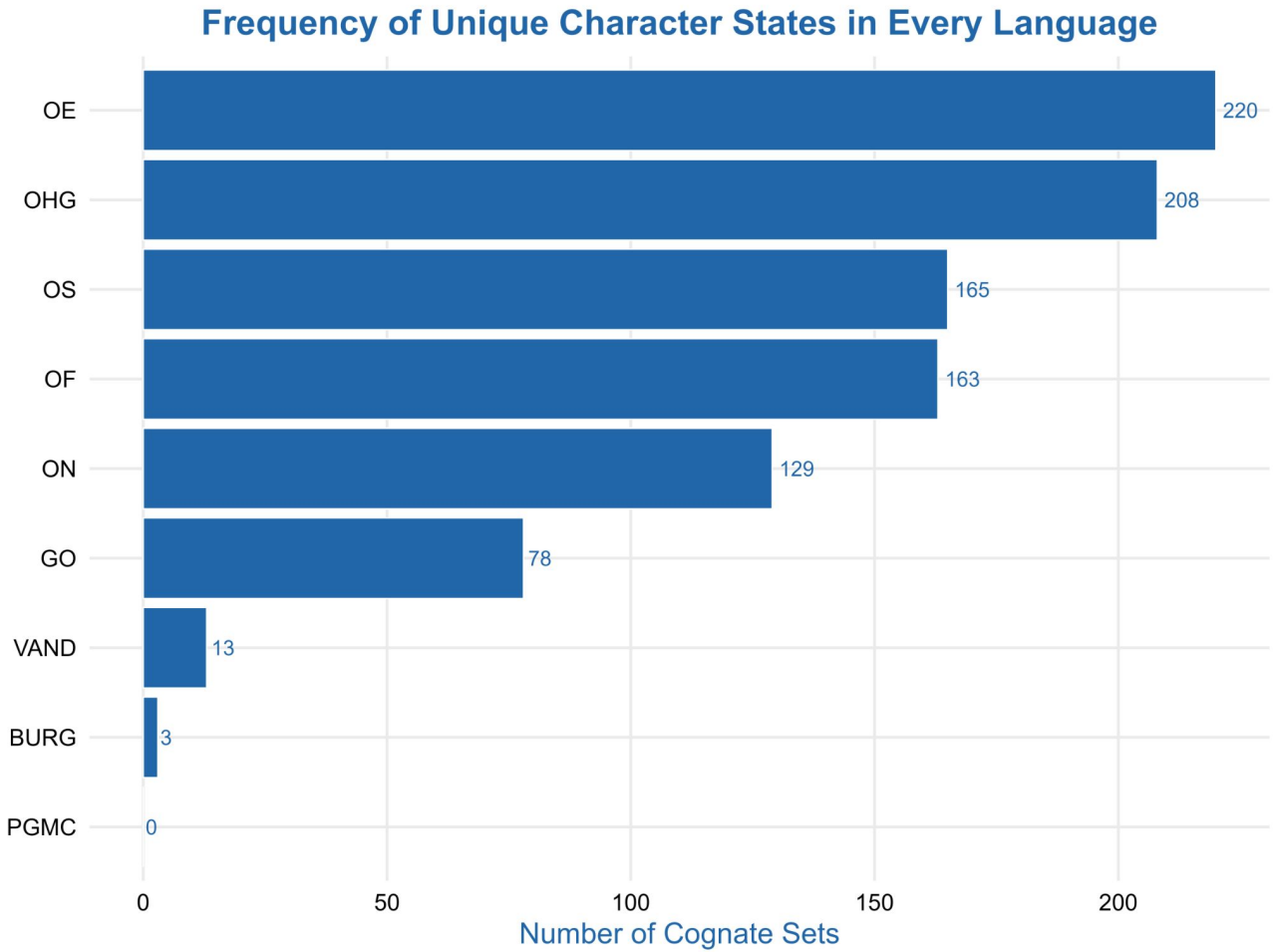
ASTRAL



MP



Bayesian


Frequency of Unique Character States in Every Language
OE
OHG
OS
OF
ON
GO
VAND
BURG
PGMC
220
208
165
163
129
78
13
3
0
0
50
100
150
200
Number of Cognate Sets

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