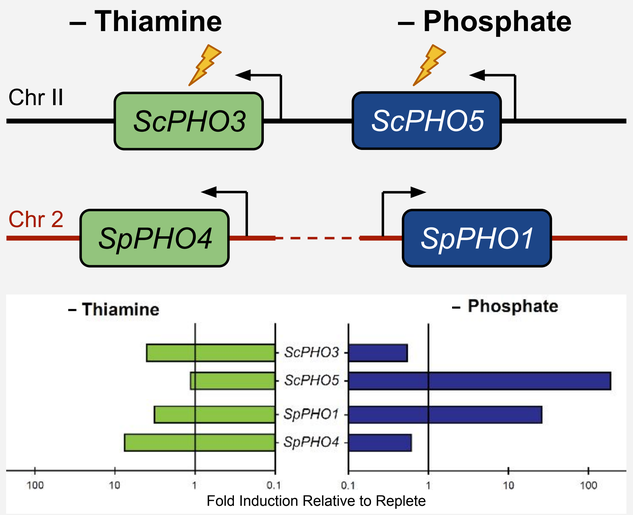
Convergent Evolution of Specialized Phosphatase Genes Following Repeated Gene Duplication and Co-Option

John V. Nahas[1], Christine L. Iosue[1], Noor F. Shaik[1], Kathleen Selhorst[1], **Bin Z. He***[, 2] , Dennis D. Wykoff*[,1]

[1] Biology Department, Villanova University, Villanova, PA; [2] Biology Department, University of Iowa, Iowa City, IA

* bin-he@uiowa.edu https://binhe-lab.org * dennis.wykoff@villanova.edu

1. Divergent yeast species similarly specialize their phosphatase genes for different starvation conditions.



***S. cerevisiae PHO5* family**

ScPHO5 responds to phosphate starvation, and *ScPHO3* to thiamine

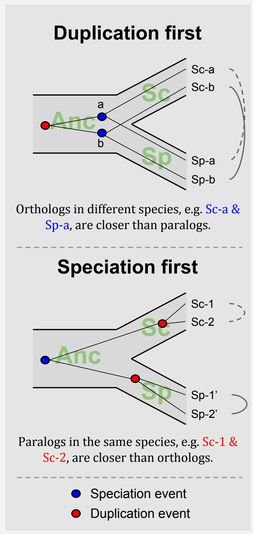
***S. pombe PHO5* family**

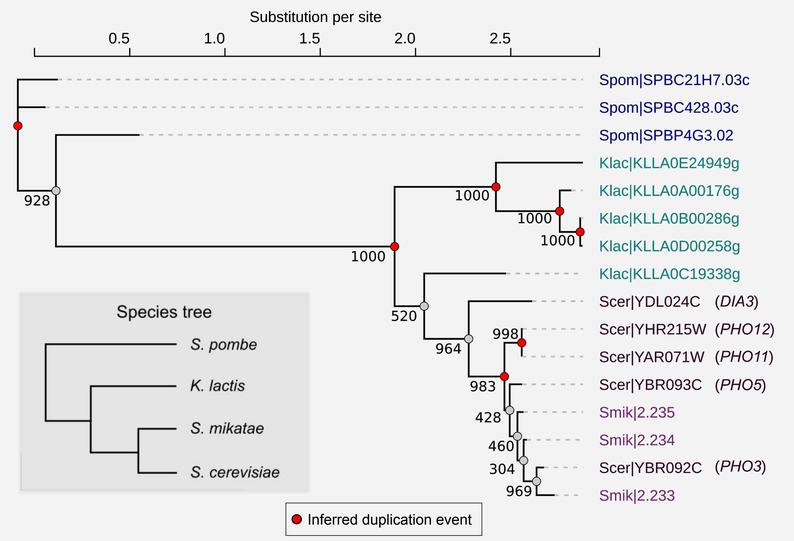
SpPHO1 and *SpPHO4* similarly specialize in phosphate vs thiamine

qRT-PCR evidence for transcriptional specialization

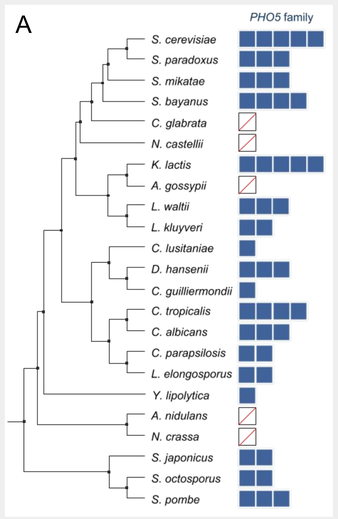
The great evolutionary distance between the two species raises the question: *is the gene duplication ancestral or independently derived?*

2. Gene duplications in the *PHO5* family in *S. cerevisiae* and *S. pombe* occurred post-speciation.





3. Gene duplications and losses in the *PHO5* family were prevalent throughout the history of the Ascomycetes.



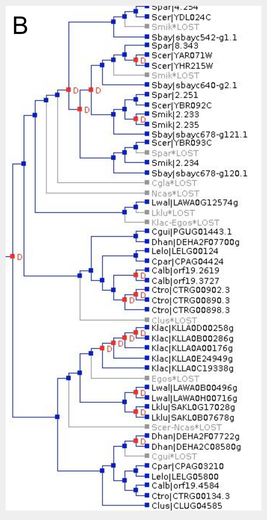
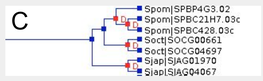


Fig. 3A The number of *PHO5* family homologs vary dramatically across the Ascomycetes (fungi).

Fig. 3B Numerous duplications (D) and losses (LOST) throughout the tree. Shown is a portion of the full tree *Reconciled tree by Notung 2.9*

Fig. 3C Another portion showing that the duplicates in *S. pombe* and closely related species occurred after they diverged from the rest of the group.



4. *C. glabrata* lost the entire *PHO5* family and co-opted a phosphomutase family to replace its function

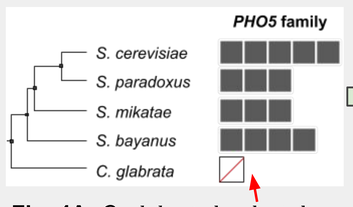


Fig. 4A *C. glabrata* has lost the entire *PHO5* family !

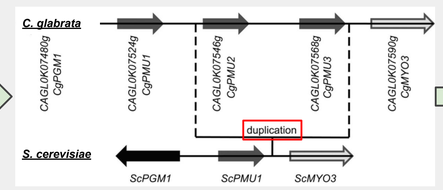


Fig. 4B Expansion of the *PMU* gene (phosphomutase) family in *C. glabrata*

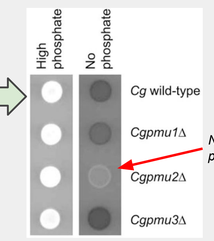


Fig. 4C *CgPMU2* encodes a secreted phosphatase like *ScPHO5*

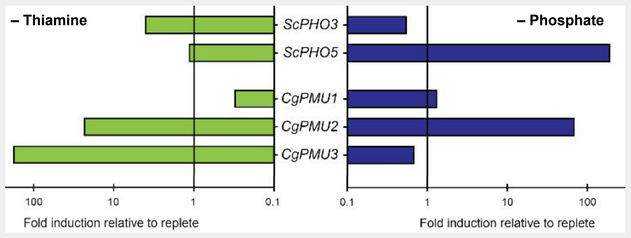
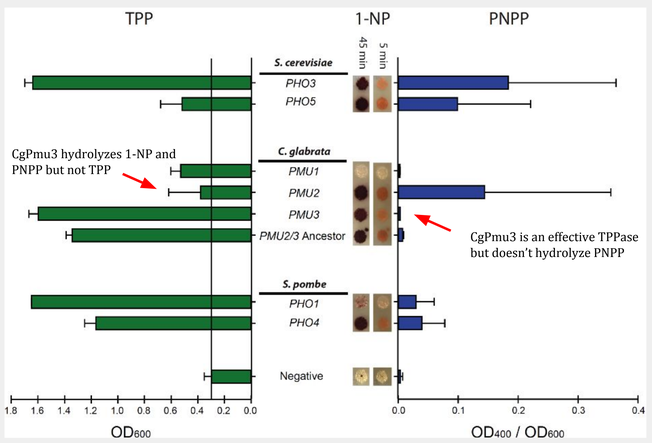


Fig. 4D *CgPMU2* and *CgPMU3* are specialized for phosphate vs thiamine, similar to *ScPHO5* and *ScPHO3*

5. *C. glabrata* specialized the *PMU* genes' activities for the substrates.



TPP Thiamine pyrophosphate is released by dead cells. Only after hydrolysis can it be imported and used as a source for thiamine

1-NP 1-napthyl phosphate is a commonly used laboratory organic phosphate. ScPho5 is known to hydrolyze it (red colonies).

PNPP p-nitrophenyl phosphate, another organic phosphates known to be hydrozyled by ScPho5.

Caveat: it's unclear what are the natural substrates for the phosphatases.

Conclusion

- ❑ Evolution of the *PHO5* family is highly dynamic, with repeated gene duplications and losses throughout the history of the diverse group of Ascomycetes.
- ❑ Different species that have independently expanded the *PHO5* families evolved *convergently* to specialize their phosphatase encoding genes for phosphate and thiamine starvations respectively at the transcriptional induction level.
- ❑ Evolution can use alternative "raw materials" when the presumably favored material is not available: *C. glabrata* co-opted a phosphomutase family, whose ancestor (Pmu1) doesn't have activities against organic phosphates and was not secreted. The co-opted CgPmu2 performs similar functions as ScPho5.

Reference

- Orkwis *et al.* "Novel Acid Phosphatase in Candida Glabrata Suggests Selective Pressure and Niche Specialization in the Phosphate Signal Transduction Pathway." *Genetics* 186, no. 3 (November 2010): 885–95.
- Nahas *et al.* "Dynamic changes in yeast phosphatase families allow for specialization in phosphate and thiamine starvation", *G3*, under review 2018