MycoCosm: KEGG Browser

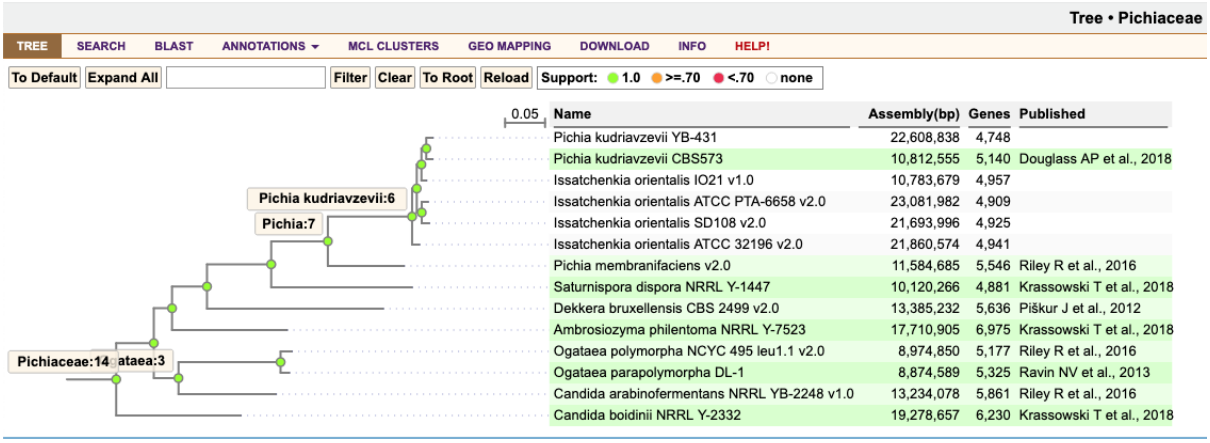
KEGG stands for Kyoto Encyclopedia of Genes and Genomes at http://www.genome.jp/kegg/, which maintains a curated set of EC-annotated enzymes and their pathways. Each portal's KEGG Browser facilitates display and discovery of MycoCosm's KEGG-annotated genes. Using the KEGG browser, one can search or browse through KEGG metabolic and regulatory pathways to retrieve information about the enzymes, pathways, and proteins associated with the KEGG annotations.

Scenario: You have plated a variety of yeasts on a variety of carbon sources, and discovered that some members of the Pichiaceae grow on galactose (e.g., *Dekkera bruxellensis*) and some do not (e.g., *Pichia membranifaciens*). Use MycoCosm to find genes that could explain this metabolic difference.

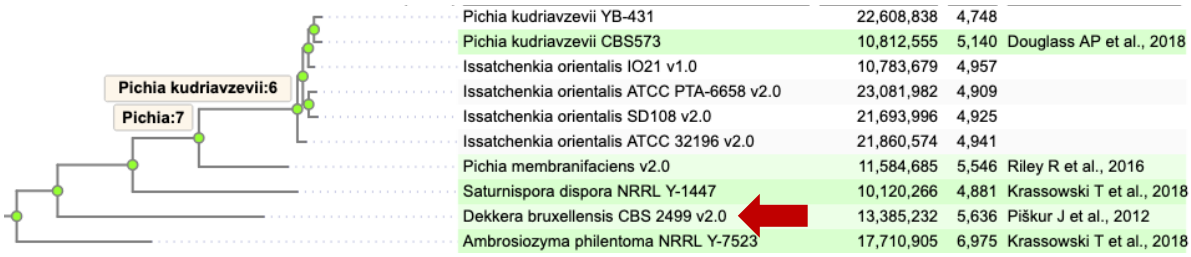
1) Go to the MycoCosm Pichiaceae PhyloGroup at mycocosm.jgi.doe.gov/Pichiaceae:

##	Name	Assembly Length	# Genes	Published
1	Candida arabinofermentans NRRL YB-2248 v1.0	13,234,078	5,861	Riley R et al., 2016
2	Candida boidinii NRRL Y-2332	19,278,657	6,230	Krassowski T et al., 2018
3	Dekkera bruxellensis CBS 2499 v2.0	13,385,232	5,636	Piškur J et al., 2012
4	Issatchenkia orientalis ATCC 32196 v2.0	21,860,574	4,941	
5	Issatchenkia orientalis ATCC PTA-6658 v2.0	23,081,982	4,909	
6	Issatchenkia orientalis IO21 v1.0	10,783,679	4,957	
7	Issatchenkia orientalis SD108 v2.0	21,693,996	4,925	
8	Ogataea parapolymorpha DL-1	8,874,589	5,325	Ravin NV et al., 2013
9	Ogataea polymorpha NCYC 495 leu1.1 v2.0	8,974,850	5,177	Riley R et al., 2016
10	Pichia kudriavzevii CBS573	10,812,555	5,140	Douglass AP et al., 2018
11	Pichia kudriavzevii YB-431	22,608,838	4,748	
12	Pichia membranifaciens v2.0	11,584,685	5,546	Riley R et al., 2016
13	Saturnispora dispora NRRL Y-1447	10,120,266	4,881	Krassowski T et al., 2018

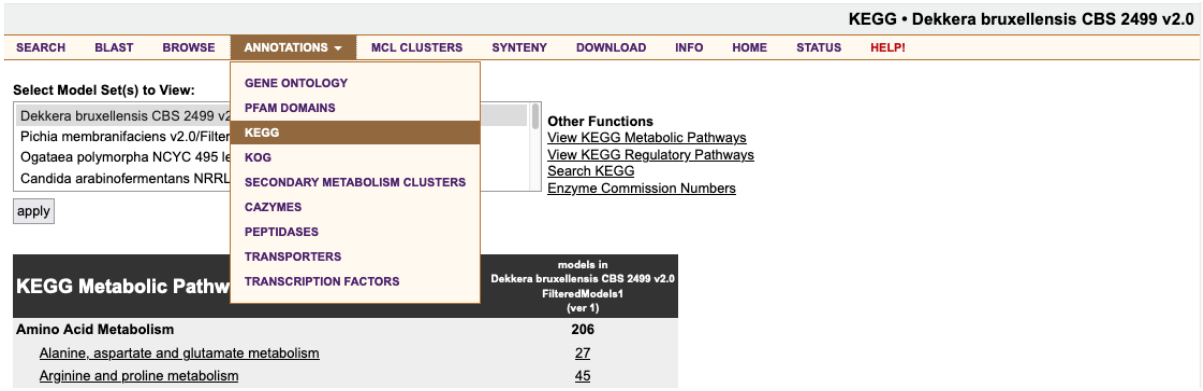
2) To verify that *Dekkera* (which grows on galactose) and *Pichia* (which does not) are sibling taxa, click on '**TREE**':



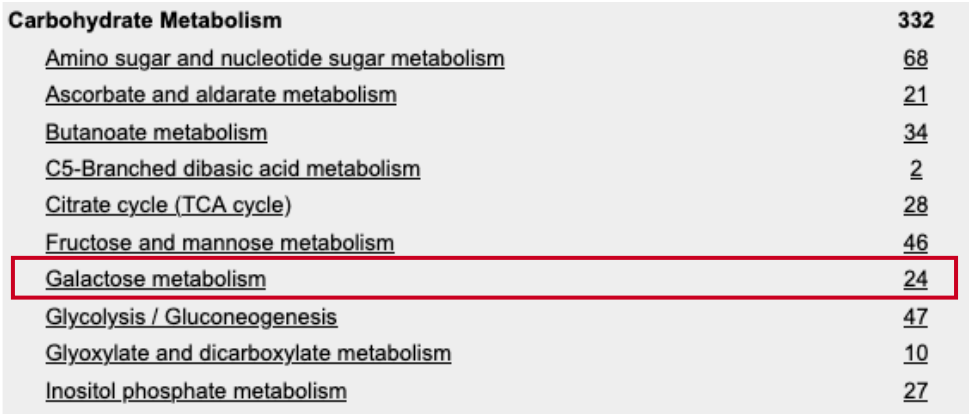
3) Click on '**Dekkera bruxellensis CBS 2499 v2.0**' to go to its genome portal:



4) Click on "**ANNOTATIONS => KEGG**" to go to the portal's KEGG browser:

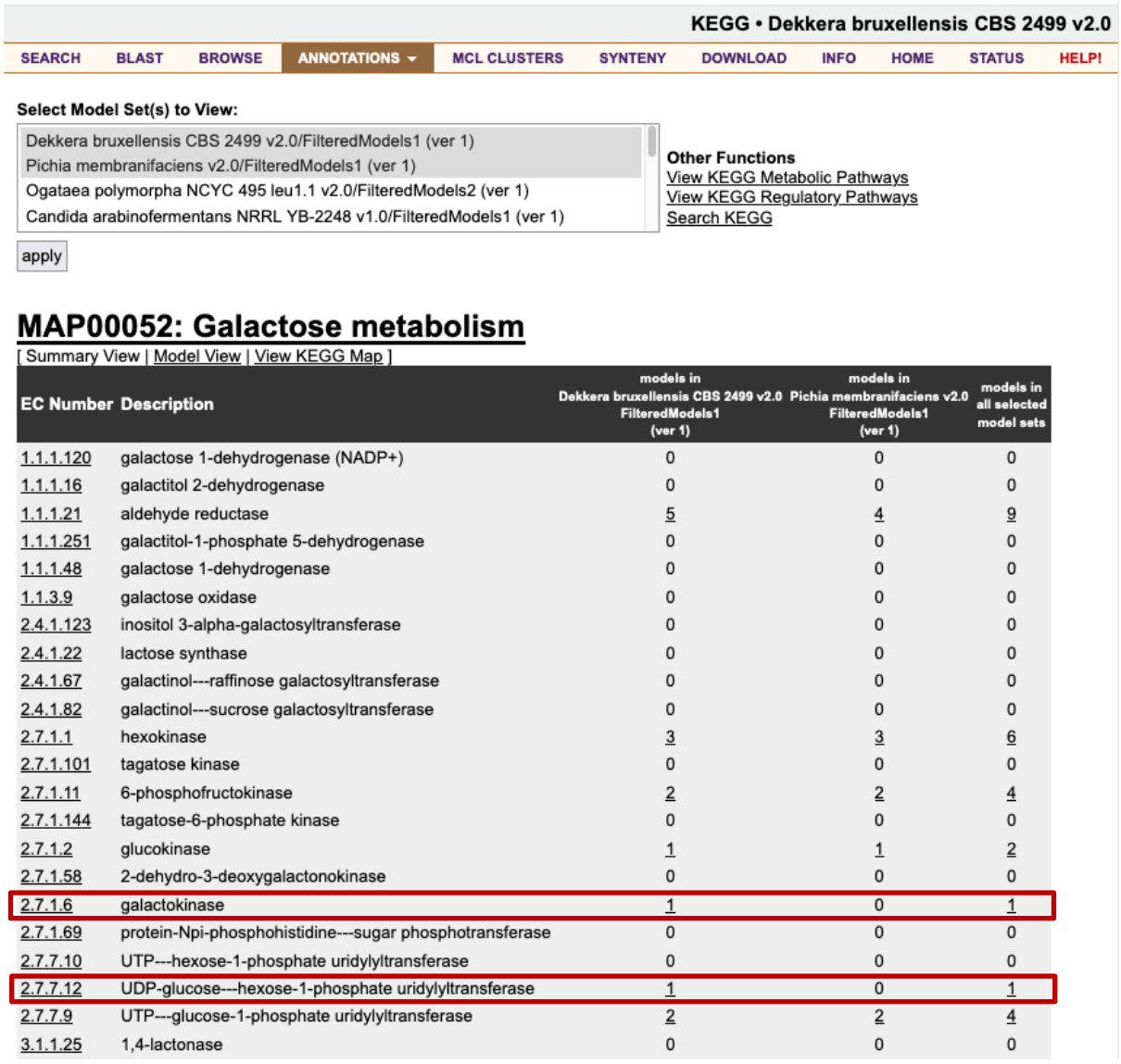


5) Scroll down to the '**Carbohydrate Metabolism**' section, and find the subsection '**Galactose metabolism**'. *Dekkera* has 24 genes annotated to this metabolic pathway:



6) Click on '**Galactose metabolism**' to drill down into the KEGG hierarchy and list the EC numbers associated with that pathway.

7) Go to the '**Select Model Set(s) to View**' list box and select *Dekkera bruxellensis* and *Pichia membranifaciens* and click the '**apply**' button. The *Dekkera* and *Pichia* galactose metabolism gene counts are side-by-side and may be directly compared. Galactokinase (EC = 2.7.1.6) and UDP-glucose--hexose-1-phosphate uridylyltransferase (2.7.7.12) are each present in *Dekkera* but not in *Pichia*:



KEGG • Dekkera bruxellensis CBS 2499 v2.0

SEARCH | BLAST | BROWSE | ANNOTATIONS | MCL CLUSTERS | SYNTENY | DOWNLOAD | INFO | HOME | STATUS | HELP!

Select Model Set(s) to View:

Dekkera bruxellensis CBS 2499 v2.0/FilteredModels1 (ver 1)
Pichia membranifaciens v2.0/FilteredModels1 (ver 1)
Ogataea polymorpha NCYC 495 leu1.1 v2.0/FilteredModels2 (ver 1)
Candida arabinofermentans NRRL YB-2248 v1.0/FilteredModels1 (ver 1)

Other Functions
View KEGG Metabolic Pathways
View KEGG Regulatory Pathways
Search KEGG

apply

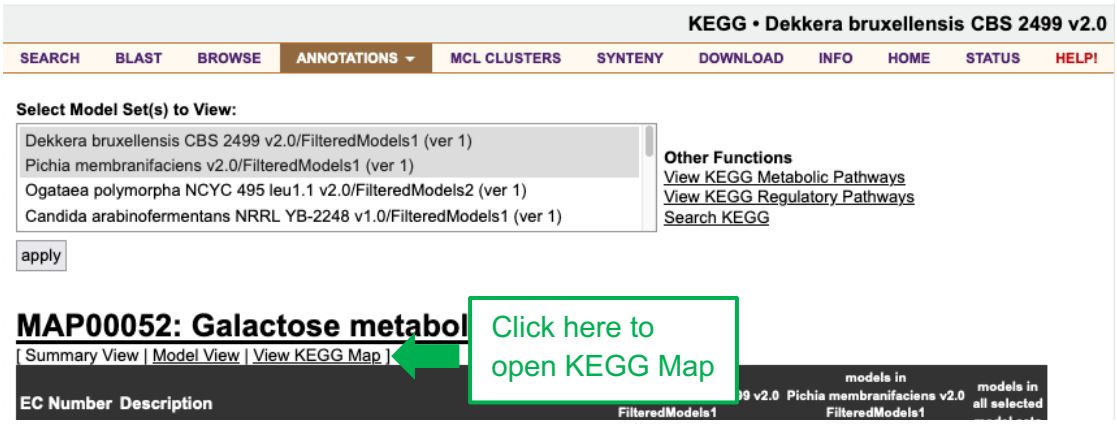
MAP00052: Galactose metabolism

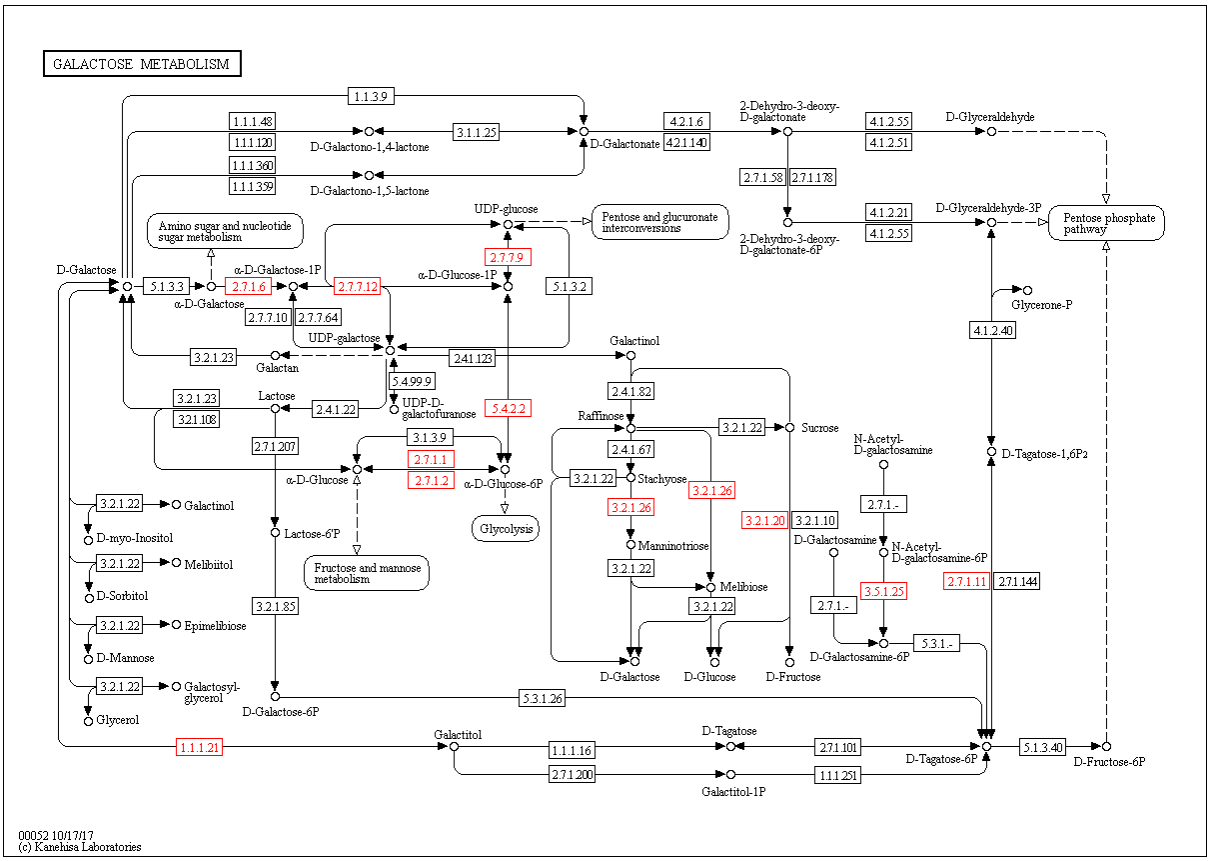
[Summary View | Model View | View KEGG Map]

EC Number	Description	models in Dekkera bruxellensis CBS 2499 v2.0 FilteredModels1 (ver 1)	models in Pichia membranifaciens v2.0 FilteredModels1 (ver 1)	models in all selected model sets
1.1.1.120	galactose 1-dehydrogenase (NADP+)	0	0	0
1.1.1.16	galactitol 2-dehydrogenase	0	0	0
1.1.1.21	aldehyde reductase	5	4	9
1.1.1.251	galactitol-1-phosphate 5-dehydrogenase	0	0	0
1.1.1.48	galactose 1-dehydrogenase	0	0	0
1.1.3.9	galactose oxidase	0	0	0
2.4.1.123	inositol 3-alpha-galactosyltransferase	0	0	0
2.4.1.22	lactose synthase	0	0	0
2.4.1.67	galactinol---raffinose galactosyltransferase	0	0	0
2.4.1.82	galactinol---sucrose galactosyltransferase	0	0	0
2.7.1.1	hexokinase	3	3	6
2.7.1.101	tagatose kinase	0	0	0
2.7.1.11	6-phosphofructokinase	2	2	4
2.7.1.144	tagatose-6-phosphate kinase	0	0	0
2.7.1.2	glucokinase	1	1	2
2.7.1.58	2-dehydro-3-deoxygalactonokinase	0	0	0
2.7.1.6	galactokinase	1	0	1
2.7.1.69	protein-Npi-phosphohistidine---sugar phosphotransferase	0	0	0
2.7.7.10	UTP---hexose-1-phosphate uridylyltransferase	0	0	0
2.7.7.12	UDP-glucose---hexose-1-phosphate uridylyltransferase	1	0	1
2.7.7.9	UTP---glucose-1-phosphate uridylyltransferase	2	2	4
3.1.1.25	1,4-lactonase	0	0	0

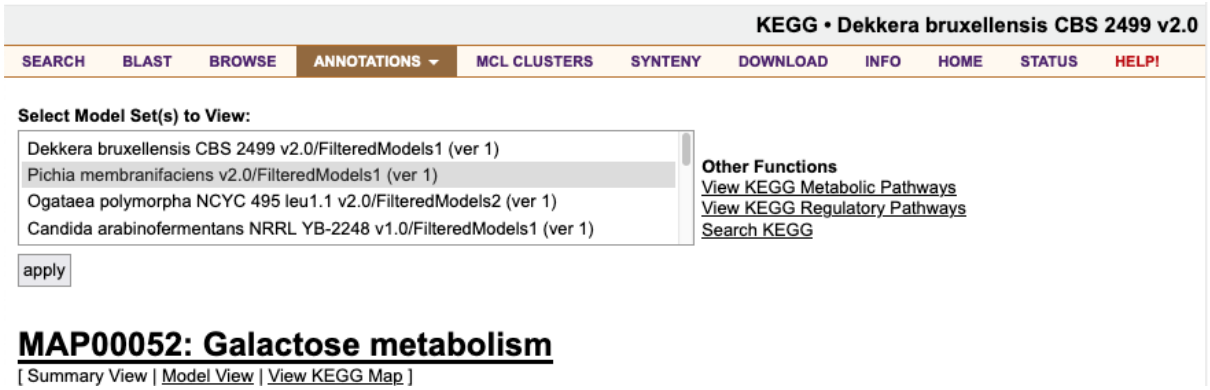
8) Scroll back up to the '**Select Model Set(s) to View**' list box and select *Dekkera bruxellensis* only. Click '**apply**' to show the *Dekkera* counts only.

9) Click '**View KEGG Map**' to see a graphical display of the pathway. Only those enzyme boxes colored red are annotated as such in *Dekkera*. These include both 2.7.1.6(Galactokinase) and 2.7.7.12 (UDP-glucose--hexose-1-phosphate uridylyltransferase):

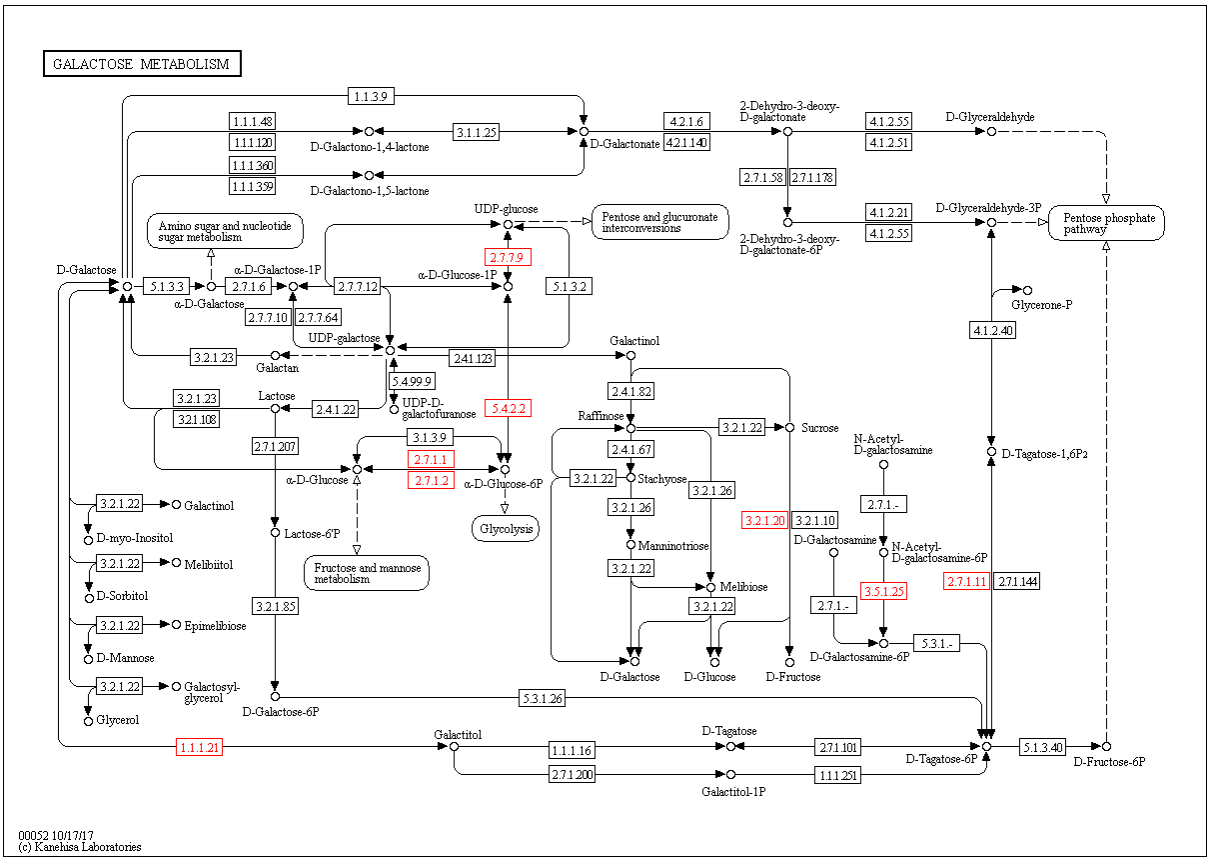




10) Use the web browser back button return to the *Dekkera* galactose metabolism page and select *Pichia* only. Click '**apply**' to show the *Pichia* counts only.



11) Click '**View KEGG Map**' again, and again only those enzyme boxes colored in red are annotated as such in *Pichia*. These include neither 2.7.1.6 nor 2.7.7.12. No wonder *Pichia* cannot grow on galactose – it is missing the genes coding for key enzymes in the galactose utilization pathway.



Exercise:

Based on the KEGG annotations, can you predict whether *Ogataea polymorpha*, *Saccharomyces cerevisiae*, and *Nadsonia fulvescens* can grow on galactose?

Reference:

- Riley R, Haridas S, Wolfe KH, Lopes MR, Hittinger CT, Göker M, Salamov AA, Wisecaver JH, Long TM, Calvey CH, Aerts AL, Barry KW, Choi C, Clum A, Coughlan AY, Deshpande S, Douglass AP, Hanson SJ, Klenk HP, LaButti KM, Lapidus A, Lindquist EA, Lipzen AM, Meier-Kolthoff JP, Ohm RA, Otillar RP, Pangilinan JL, Peng Y, Rokas A, Rosa CA, Scheuner C, Sibirny AA, Slot JC, Stielow JB, Sun H, Kurtzman CP, Blackwell M, Grigoriev IV, Jeffries TW. Comparative genomics of biotechnologically important yeasts. Proc Natl Acad Sci U S A. 2016 Aug 30;113(35):9882-7. doi: 10.1073/pnas.1603941113. Epub 2016 Aug 17. PubMed PMID: 27535936; PubMed Central PMCID: PMC5024638.