

Supplemental Materials

Molecular Biology of the Cell

Grant et al.

Supplemental Figure 1. FACS data confirms the synchronicity of U2OS cells after release from thymidine or nocodazole. A-C) FACS data from select timepoints from the double thymidine arrested cells shows a population of synchronous cells. D) Thymidine-nocodazole arrested cells are synchronous after release as shown by select timepoint FACS analysis.

Supplemental Figure 2. Genes removed by spectral clustering. A) K-means clustering Power spectra of the first two principal components for each gene called as being cell cycle regulated. Blue indicates genes that passed this filtering step, red indicates genes that did not pass and were removed from further analysis. B) The expression profiles of genes that were removed due to this filtering step.

Supplemental Figure 3. The correlation scores of cell cycle regulated genes in U2OS cells show differences with HeLa cells. A) The correlation scores of all cell cycle regulated genes to the "idealized vectors" (see Figure 1) in U2OS cells after hierarchical clustering. B) The cell cycle regulated gene correlations for HeLa cells after hierarchical clustering.

Supplemental Figure 4. The Expression profiles of genes bound by FOXM1. The clustered Expression profile of the 1582 genes that are bound by FOXM1 that are not cell cycle regulated in U2OS and HeLa cells.

Supplemental Figure 5. FOXM1 binds to the promoters of previously published FOXM1 target genes. A) The FOXM1 binding profile of AURKB for each of two ChIP-seq runs. B) The FOXM1 binding profile of CCNB1 for each of the ChIP-seq runs. C) The binding profile of CCNB2 for the two FOXM1 ChIP-seq runs. D) The Profiles for PLK11 for each of the ChIP-seq runs. E) The FOXM1 binding profiles of TOP2A for both ChIP-seq runs. All binding profiles were visualized on the UCSC genome browser (<http://genome.ucsc.edu/>)

Supplemental Figure 6. FOXM1 ChIP-seq identifies a subset of previously published targets. A) Previously published FOXM1 targets that were confirmed by FOXM1 ChIP-seq in HeLa cells. Genes were ordered by the percent coverage of their promoters. B) FOXM1 target genes that were identified by chromatin immunoprecipitations in epithelial cell lines that were not found in this study. See Supplemental Table 4 for references. C) Displaying transcription factor binding as percent coverage of gene model regions. A. The gene model for the FOXM1 target cyclin B2 as defined by the UCSF genome browser divided into regions. Two regions of FOXM1 binding are indicated by large rectangles. B. The gene model from part A displayed as a heat map of percent coverage. In addition to the 1000bp window size depicted in part A, region sizes of 3000bp and 2000bp are also displayed in the heat map display.

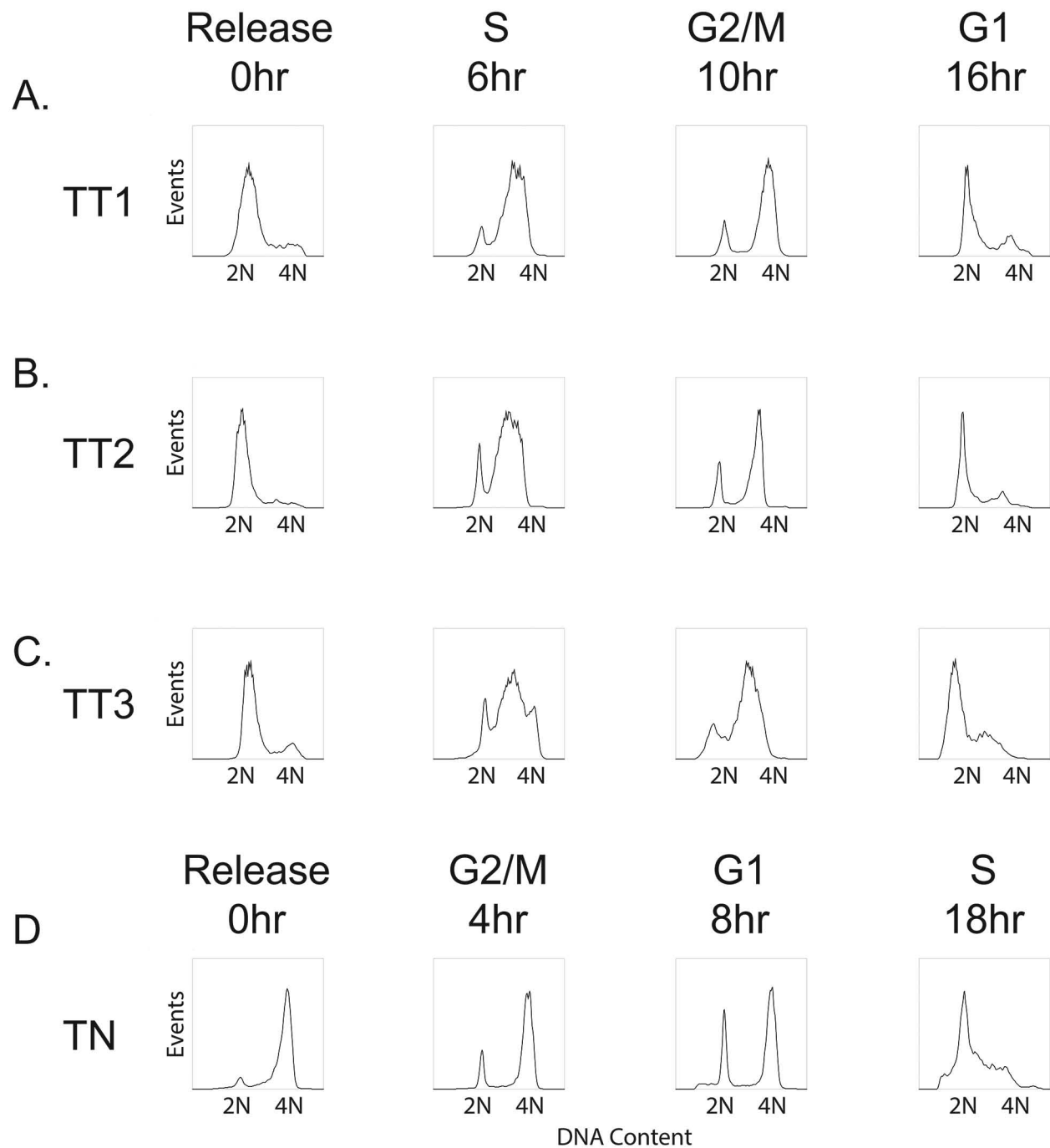
Supplemental Figure 7. The expression profiles of the 12 previously published FOXM1 targets that we did not verify by ChIP-seq. The expression profiles of the previous published chromatin immunoprecipitated FOXM1 target genes.

Supplemental Figure 8. The expression profiles of the 96 cell cycle regulated genes in HeLa cells, U2OS cells, foreskin fibroblasts, and HaCaT cells. The clustered expression profiles and ENCODE data for the 96 genes that were cell cycle regulated in four independent cell types. Foreskin fibroblast and HaCat data was mean centered for display purposes (Bar-Joseph et al. 2008) (Pena-Diaz et al. 2013). Double thymidine (TT), thymidine nocodazole (TN), and Serum thymidine (S-T) synchronizations are shown. Note, the five gray bars in the HeLa datasets indicate these genes were not included in the two time courses selected for display, but the genes were identified as cell cycle regulated in the original publication (Whitfield et al. 2002).

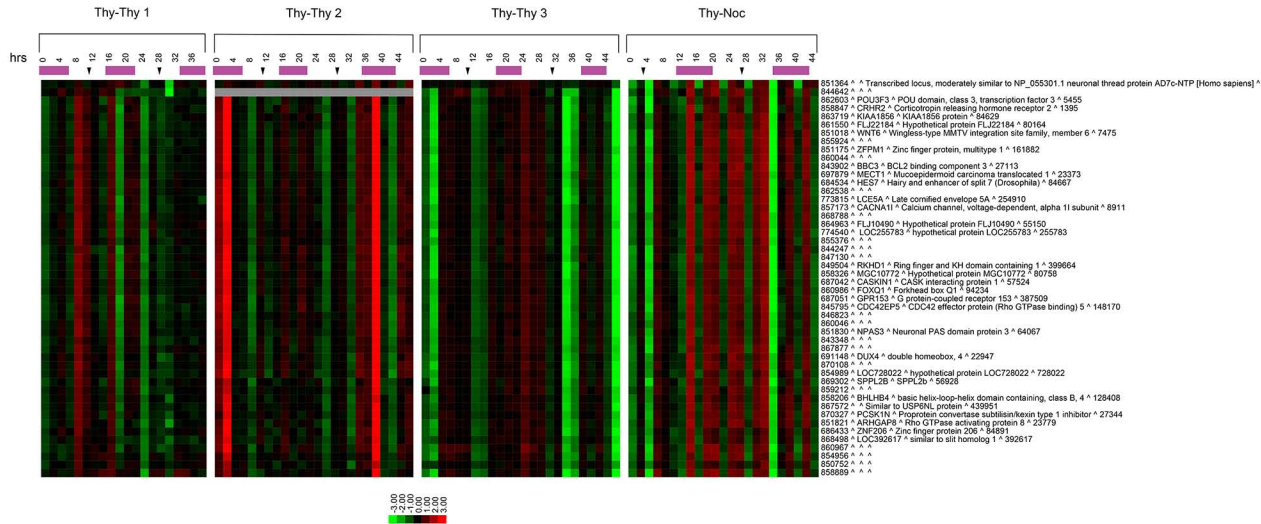
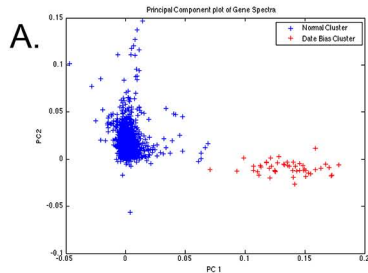
Supplemental Figure 9. The estimated percent false discovery rate (FDR) for the analysis using the double thymidine time courses only (grey line) or all time courses (black line). Data was randomized by rows and columns to estimate the FDR (see materials and methods).

Supplemental Figure 10. Alternate color scheme for Figures 1 – 8 from the main text. Each figure showing gene expression data is presented here in a Blue / Yellow color format.

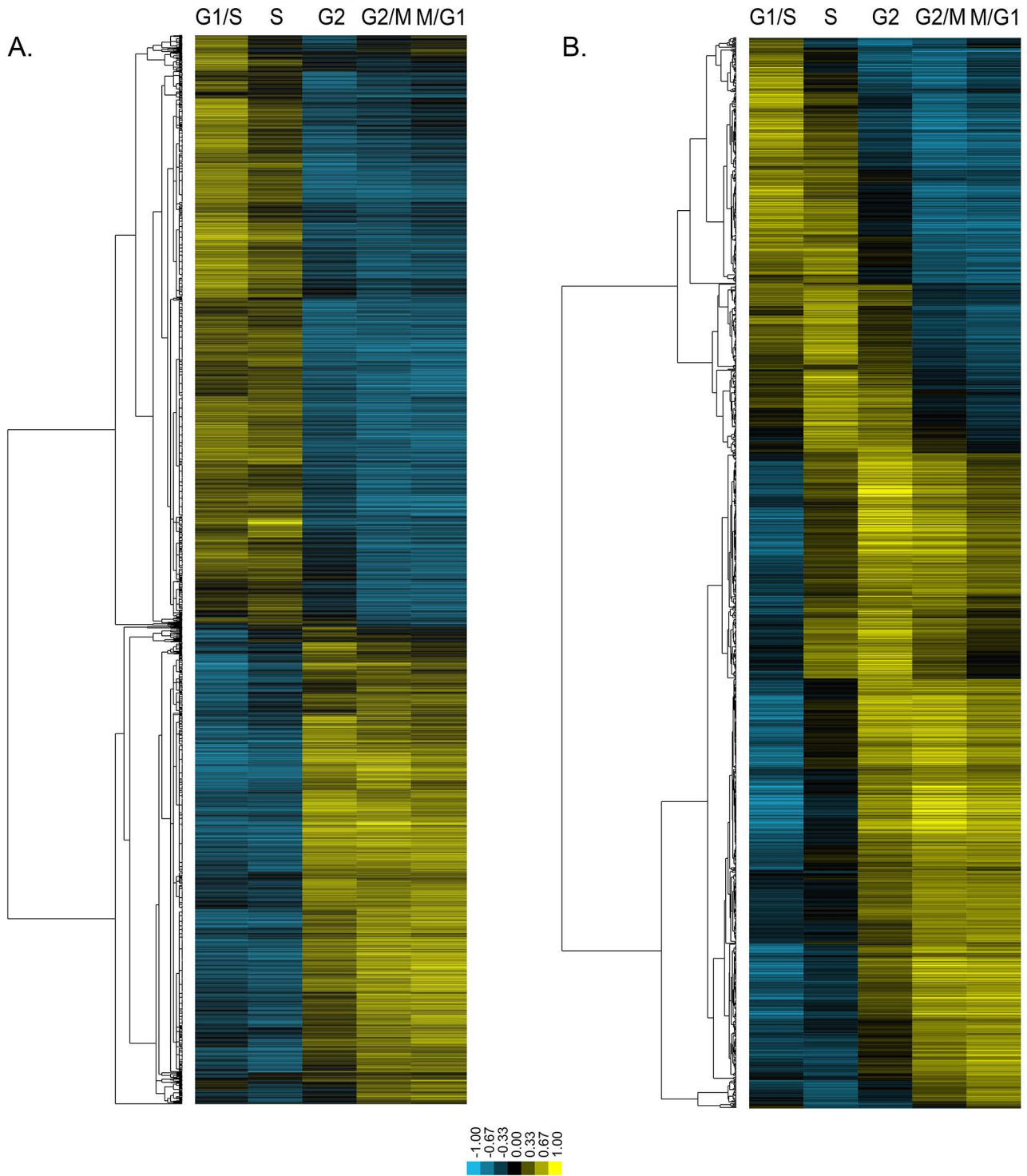
Supplemental Figure 1

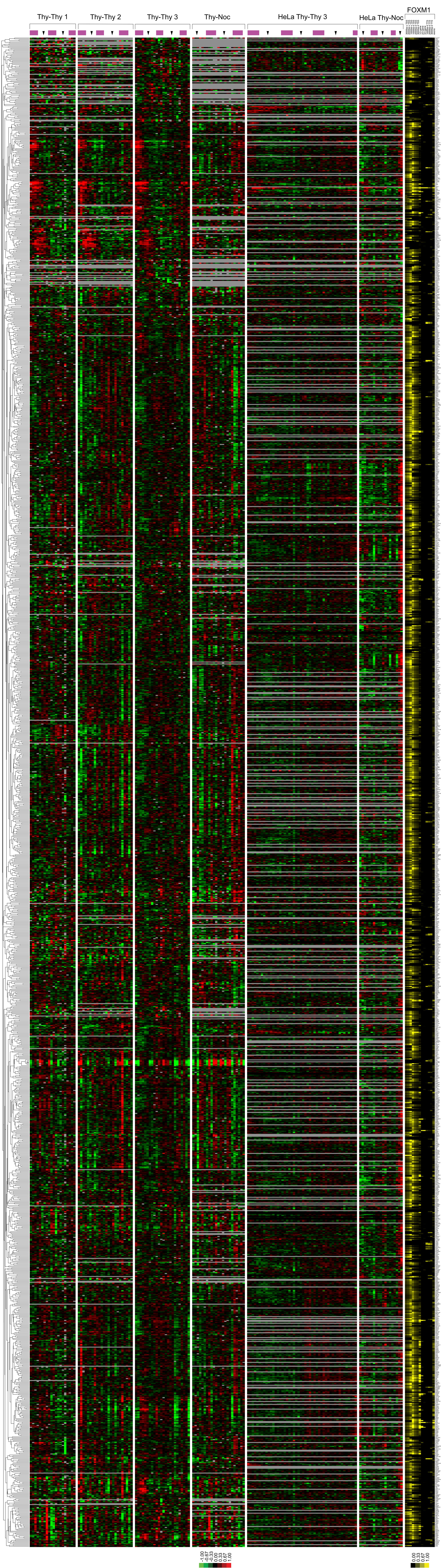


Supplemental Figure 2



Supplemental Figure 3

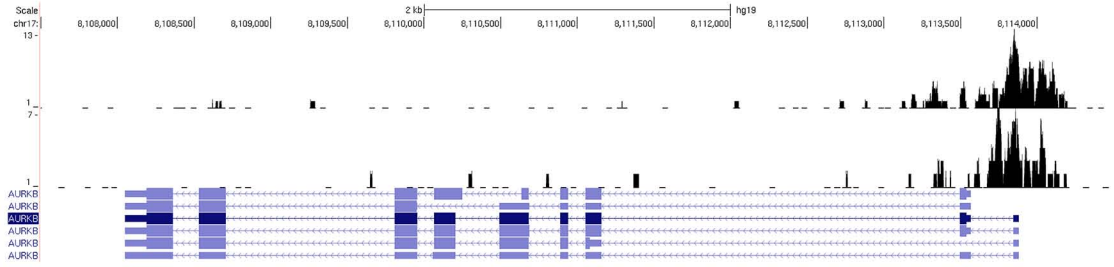




Supplemental Figure 5

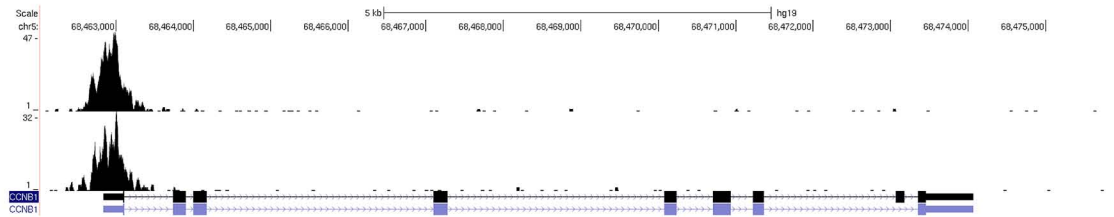
A.

AURKB



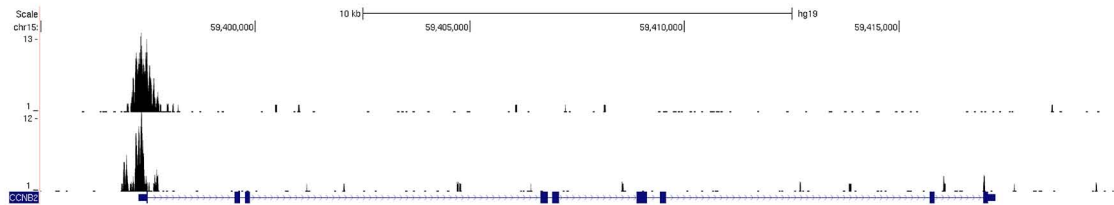
B.

CCNB1



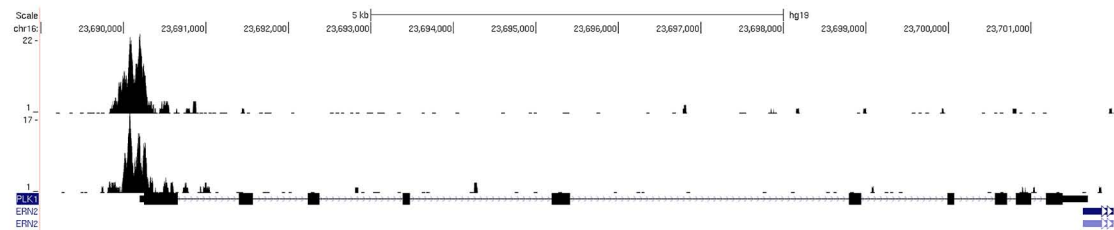
C.

CCNB2



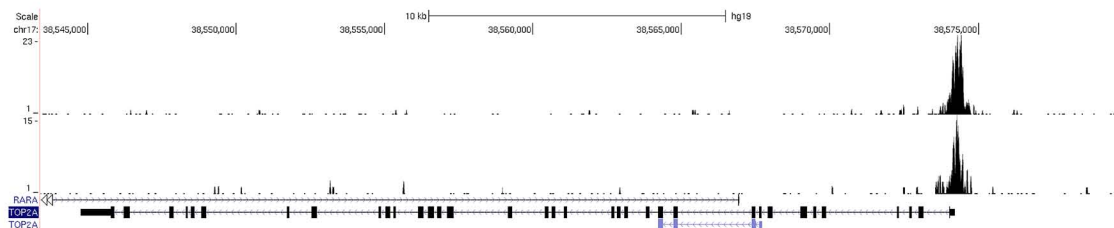
D.

PLK1



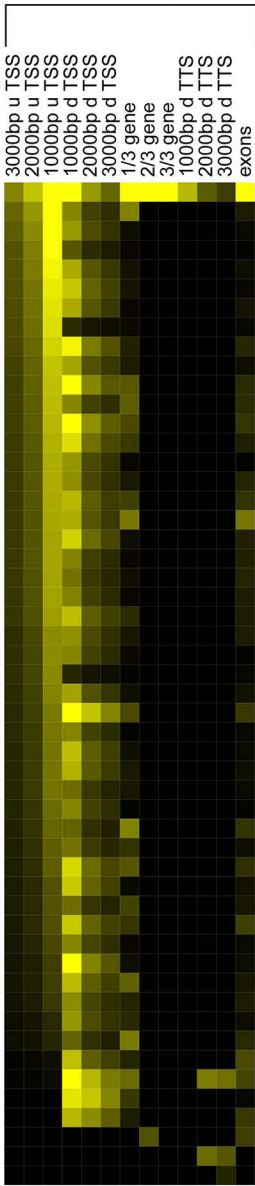
E.

TOP2A



A

FOXM1
ChIP-seq
Coverage



- Symbol**
- NFκB-p65 (RELA)
 - HMGB2
 - BORA
 - CCNF
 - PRC1
 - TOPO 2α (TOP2A)
 - DTL
 - CCNG2
 - AURKA
 - HJURP
 - KIF20A
 - CDC20
 - PLK1
 - CCNB1
 - CENPF
 - CDCA8
 - CENPA
 - UBEC (UBE2C)
 - NUSAP1
 - CDCA2
 - KAP (CDKN3)
 - CDC25C
 - NEK2
 - CCNB2
 - SMC4L1 (SMC4)
 - E2F2
 - CEP55
 - TYMS
 - Brip1 (BRIP1)
 - RACGAP1
 - MCM3
 - KIF22
 - CENPE
 - H2AFZ
 - PTTG1
 - CCNA2
 - BUBR1 (BUB1B)
 - SOX4
 - GMNN
 - POLD3
 - ANLN
 - AURKB
 - BIRC5
 - PRDX3
 - Hsp70 (HSPA1A)
 - PPIL5 (LRR1)
 - CDC25B
 - PHF19
 - CHK1 (CHEK1)
 - PCNA
 - ELF3
 - p27KIP1 (CDKN1B)

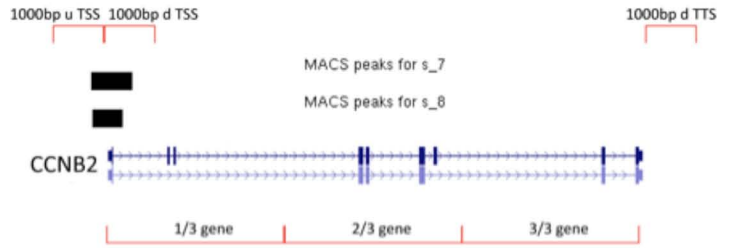
B



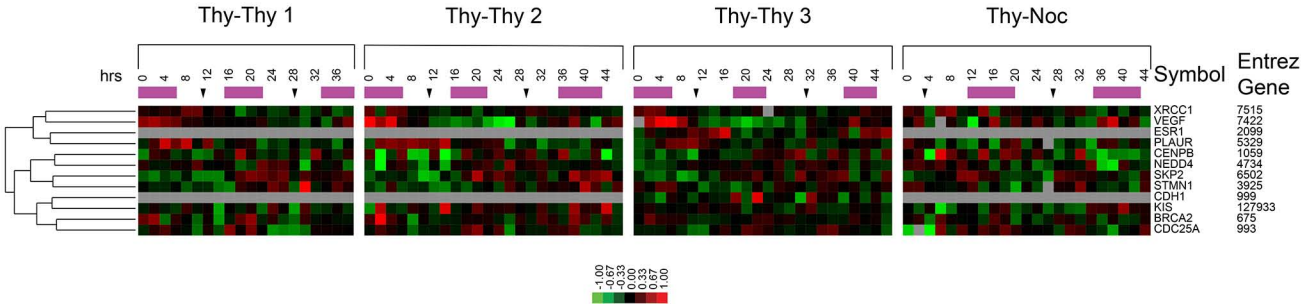
Percent Coverage



C



Supplemental Figure 7



U2OS

HeLa

Foreskin
fibroblasts

HaCaT

FOXM1

E2F1

E2F4

E2F6

GABPA

FOXK1

TT 1

TT 2

TT 3

TN

TT 3

TN

S-T

TT 1

TT 2

TT 3

Entez
Gene

Symbol

COC20 991
 IREB3 27338
 PTTG1 9232
 BRCS 332
 ARLBP 23204
 CDC46 55143
 CDC43 83461
 COC29C 995
 CKS2 1184
 DLG7 9787
 CCNB1 891
 PLK1 5347
 TOP2 22974
 CCNB2 9133
 BUB1 689
 NEC1 4751
 FLJ10156 54476
 CENPF 1093
 CENPE 1082
 SPAC5 10818
 MKI67 4288
 GTSB1 51512
 GPSM2 29899
 C10orf3 55165
 PRC1 3095
 HMG83 3149
 SRAO3 54903
 KIF2C 11004
 ESPL1 9700
 TROAP 10024
 KIF22 3633
 CCNP1 6916
 TACC3 10460
 COC28B 894
 KNTC2 16403
 NUSAP1 51303
 SHCBP1 78901
 ARHGAP19 84685
 E2F5 1875
 LBR 3830
 HMHR 3181
 MPHOSPH1 9585
 ARHGAP11A 9834
 SFPO 6421
 ANP32E 9121
 Cep70 89321
 HMG82 3148
 BRD8 15902
 TOPK 55872
 CDKN2C 1031
 BUB3 9184
 LBEC2 11085
 TOP2A 7153
 KIF18A 3838
 GPR126 57211
 KIF17 3074
 KIF23 9493
 CENPA 1028
 TTK 7272
 CKAP2 26586
 CCNA2 893
 BUB1B 791
 RIF1 3832
 CKS1B 1163
 CCNE 899
 DNFB2a762E1312 899
 HIST1H4C 8364
 CENP 4174
 E2F1 1869
 COC25A 893
 SLBP 7884
 RCM2 4171
 UNG 7374
 DDC1 79076
 PLOD3 10714
 RFC4 5984
 PCNA 9111
 Ckap776 89010
 MCM6 4176
 FLJ20516 54982
 CDC8 966
 RAMP 51514
 CCNE1 898
 CHAF1A 10038
 CHAF1B 8208
 CCNE2 9134
 AH1 54808
 PMSK 23178
 HSP88 20353
 SLC38A2 54407
 FRM1 557
 RFC2 5982
 FDX1 9156
 RRM2 6241
 BARD1 580
 C14orf130 55148



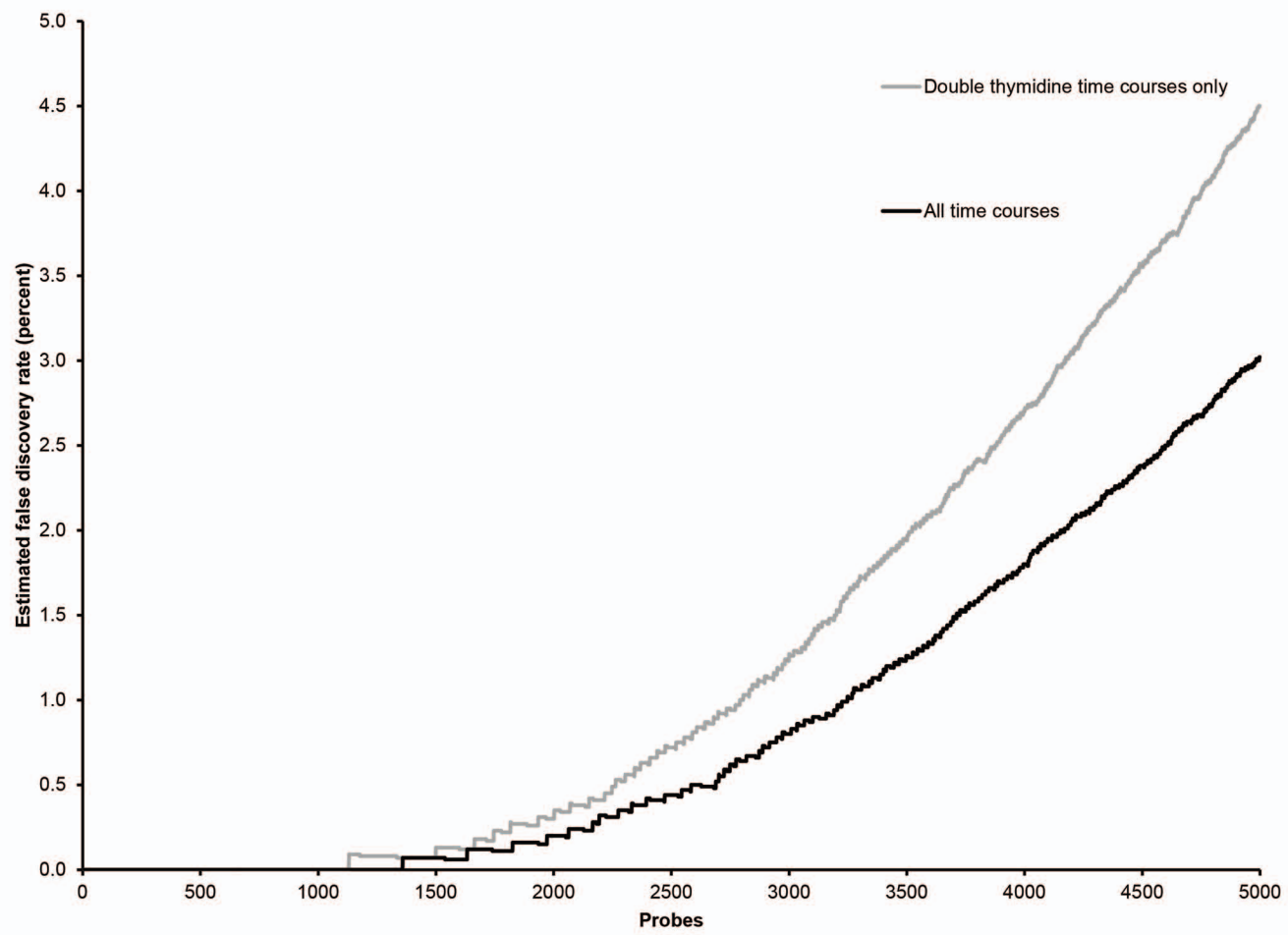
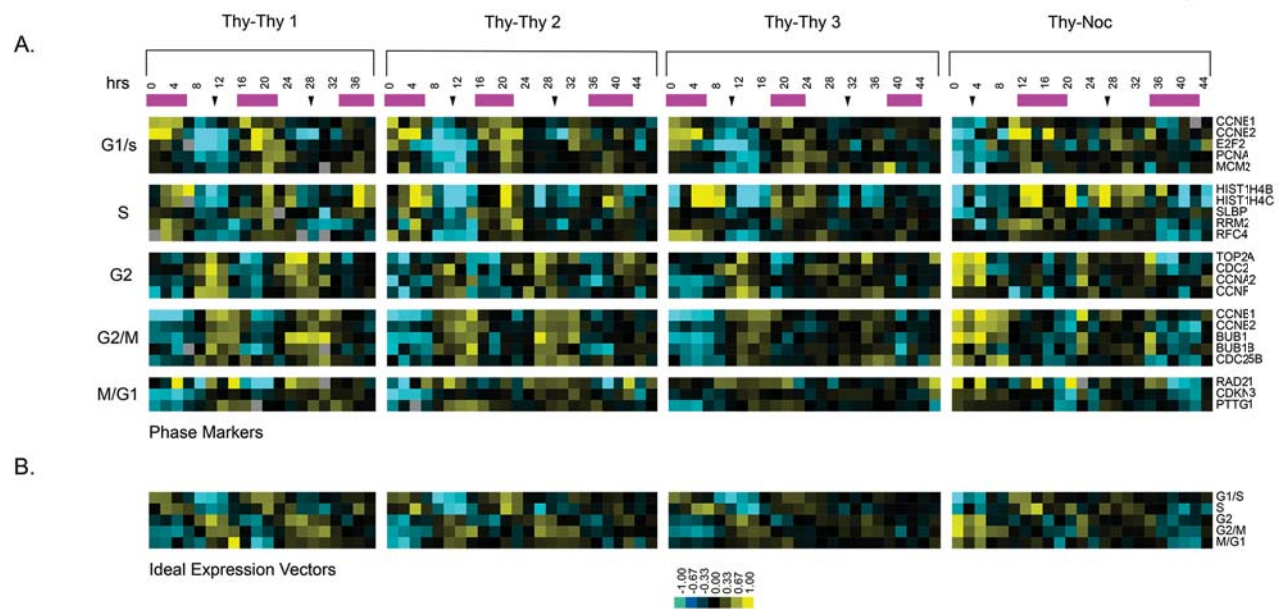


Figure 1



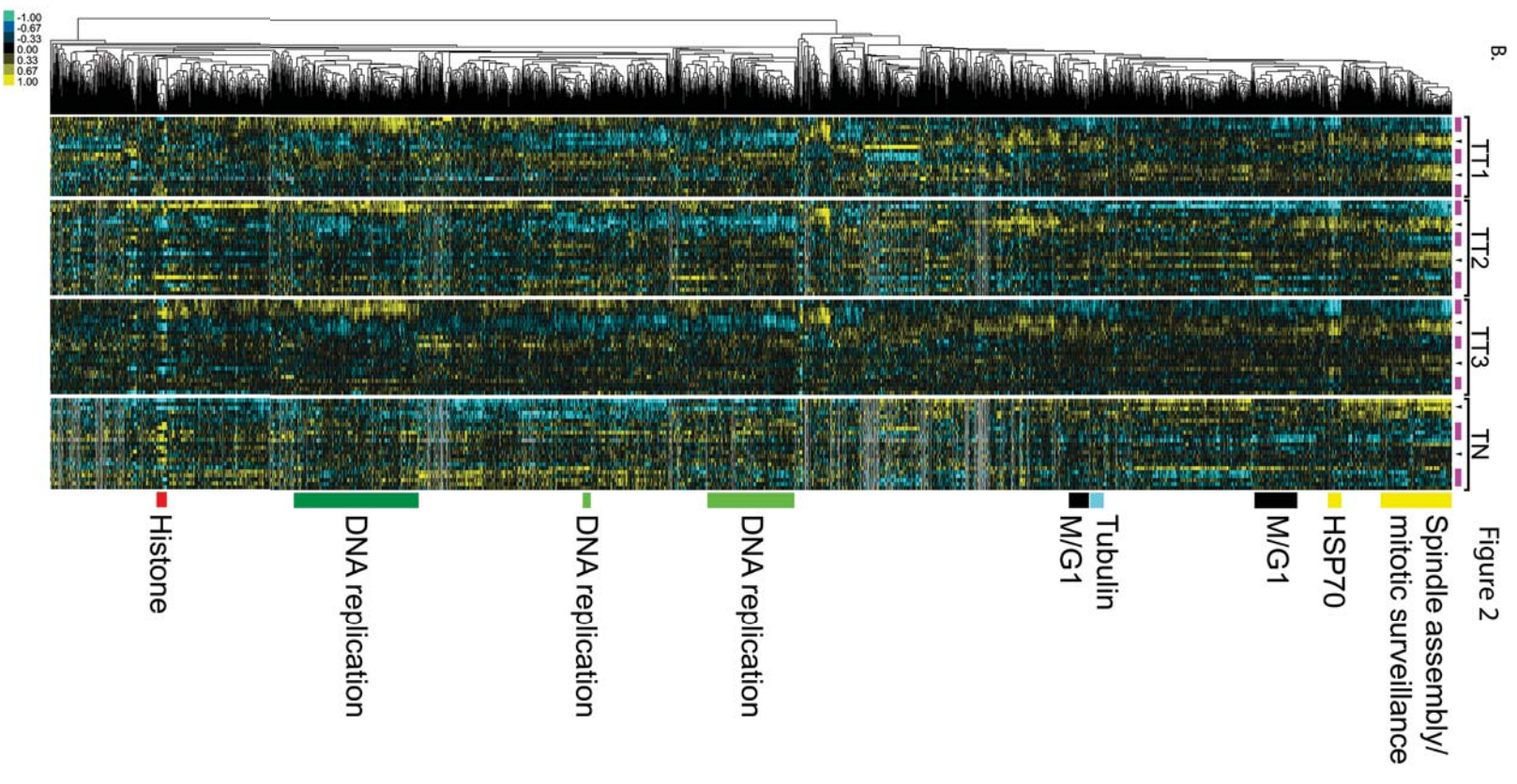
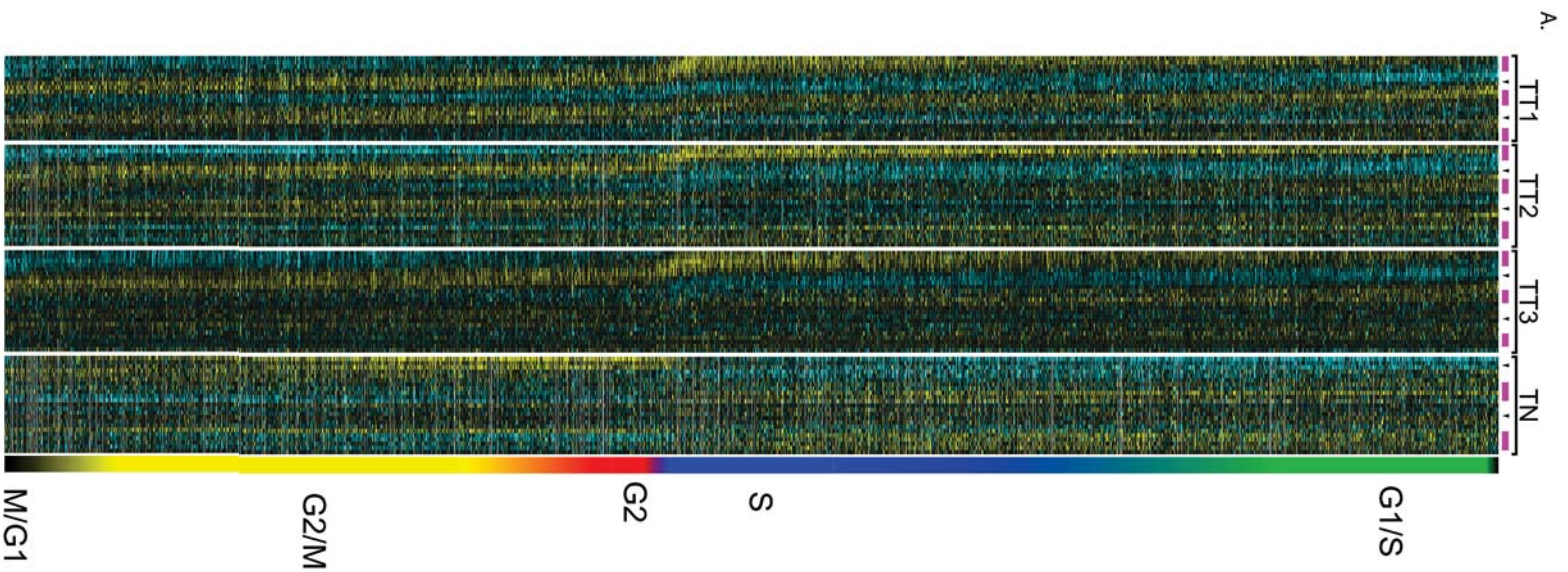


Figure 2

A.

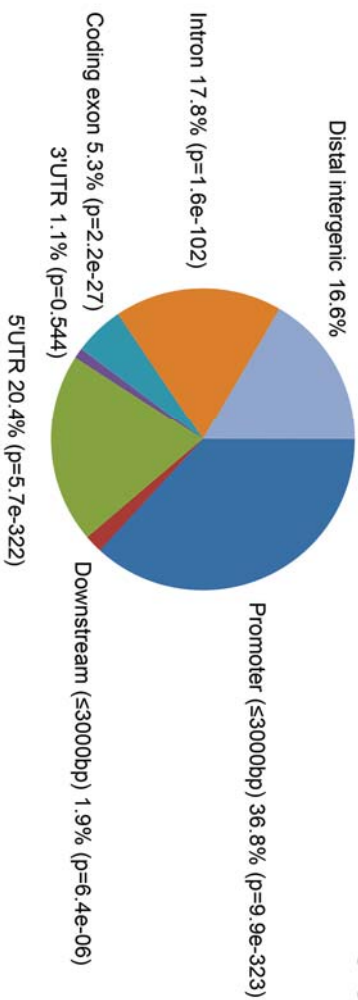
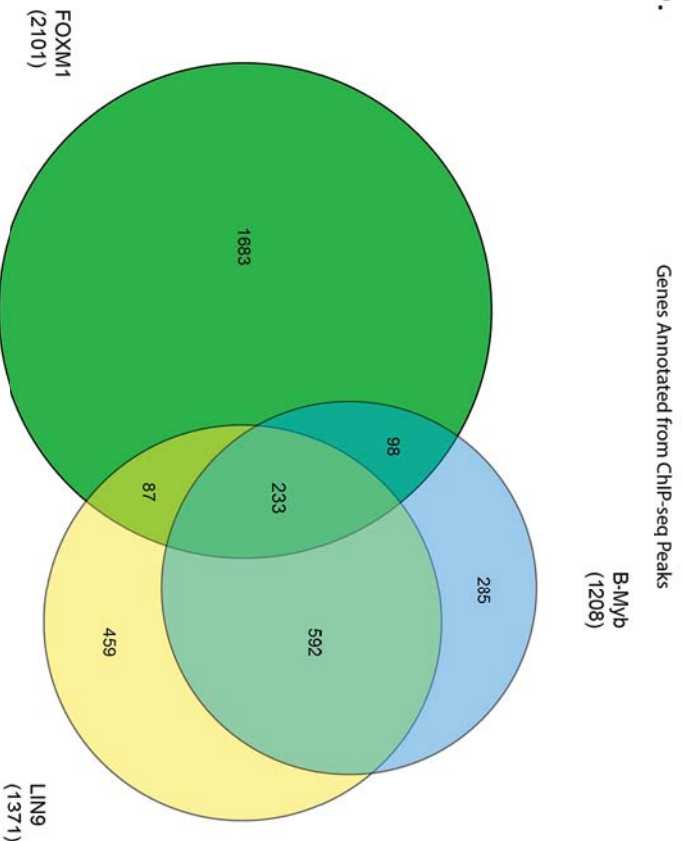


Figure 3

B.

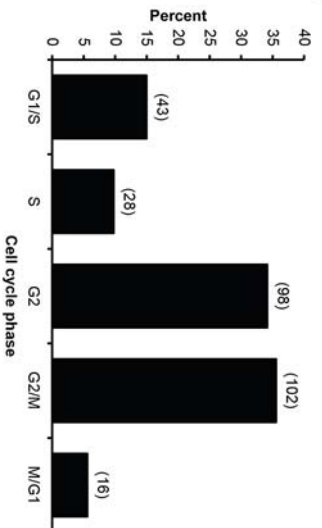


DAVID Analysis

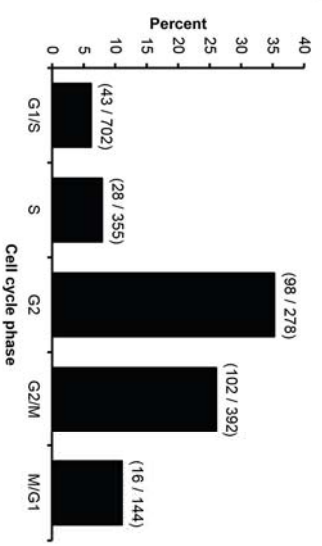
| | | |
|------------------------|---|----------|
| FOXM1 only | | |
| BP | 1. Translation | 3.49E-46 |
| CC | 2. Translational elongation | 1.32E-27 |
| | 1. Intracellular organelle lumen | 3.04E-51 |
| | 2. Ribonucleoprotein complex | 8.86E-51 |
| FOXM1 and B-Myb | | |
| BP | 1. Cell Cycle | 5.35E-06 |
| CC | 2. Mitotic Cell Cycle | 1.47E-05 |
| | 1. Intracellular non-membrane-bounded organelle | 4.81E-09 |
| | 2. Non-membrane-bounded organelle | 4.81E-09 |
| FOXM1, B-Myb, and LIN9 | | |
| BP | 1. M phase | 3.26E-39 |
| CC | 2. Nuclear Division | 3.81E-38 |
| | 1. Spindle | 7.95E-28 |
| | 2. Chromosome | 2.51E-27 |
| FOXM1 and LIN9 | | |
| BP | 1. Cell Division | 6.36E-05 |
| CC | 2. M phase | 8.12E-04 |
| | 1. Chromosome | 7.29E-04 |
| | 2. Chromosomal part | 1.26E-03 |
| B-Myb only | | |
| BP | 1. Regulation of growth | 1.60E-02 |
| CC | 2. Interphase of mitotic cell cycle | 2.09E-02 |
| | 1. Centrosome | 1.84E-02 |
| | 2. Cytosol | 2.11E-02 |
| B-Myb and LIN9 | | |
| BP | 1. Actin cytoskeleton organization | 8.18E-05 |
| CC | 2. Actin filament-based process | 1.90E-04 |
| | 1. Cytoskeleton | 2.94E-05 |
| | 2. Actin cytoskeleton | 2.96E-05 |
| LIN9 only | | |
| BP | 1. Cell adhesion | 9.56E-04 |
| CC | 2. Biological adhesion | 9.73E-04 |
| | 1. Cytoskeleton | 1.11E-04 |
| | 2. Cell-cell junction | 3.48E-04 |

Gene Ontology Functional Annotation

C.



D.



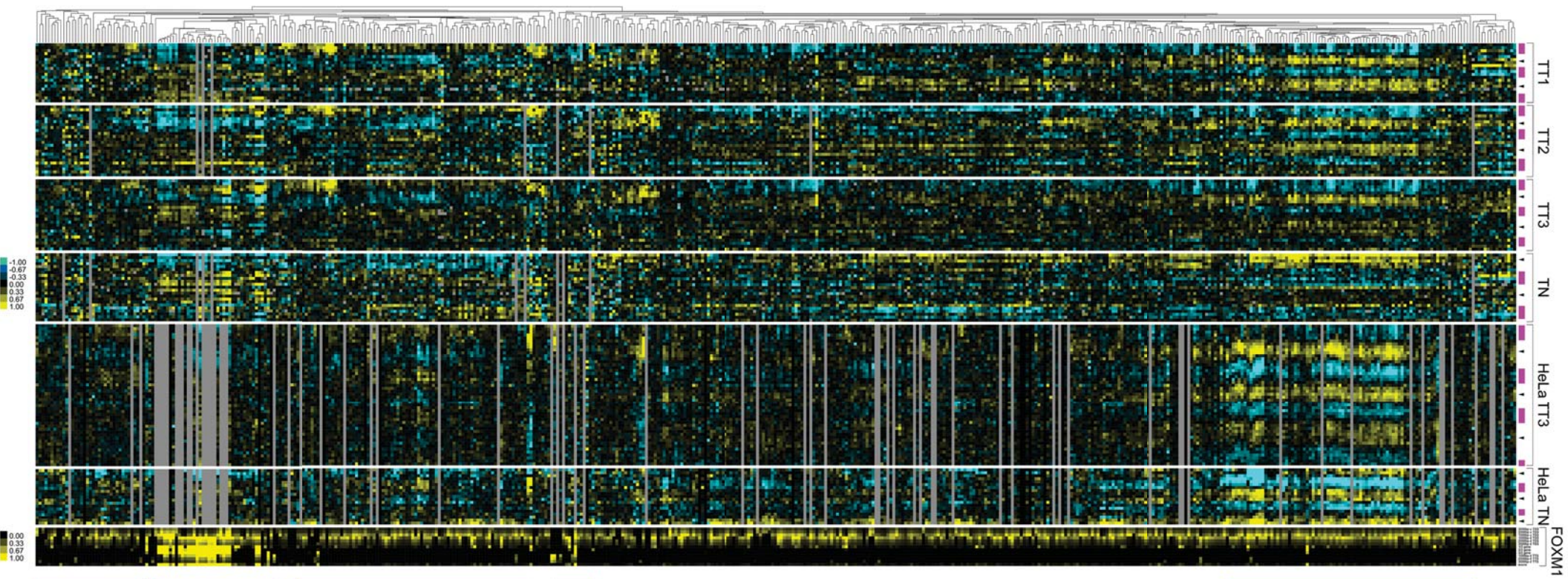
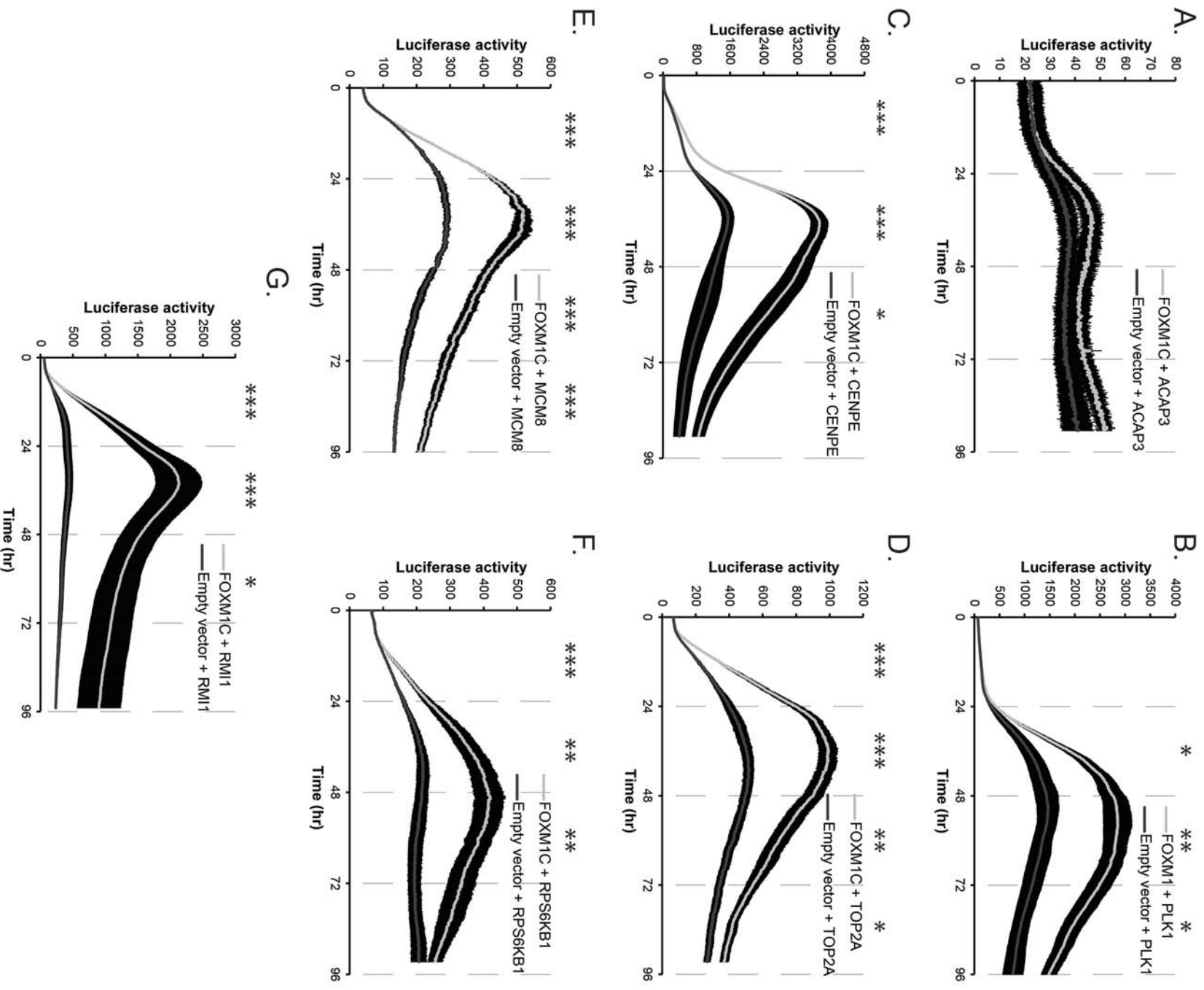


Figure 4

Figure 5



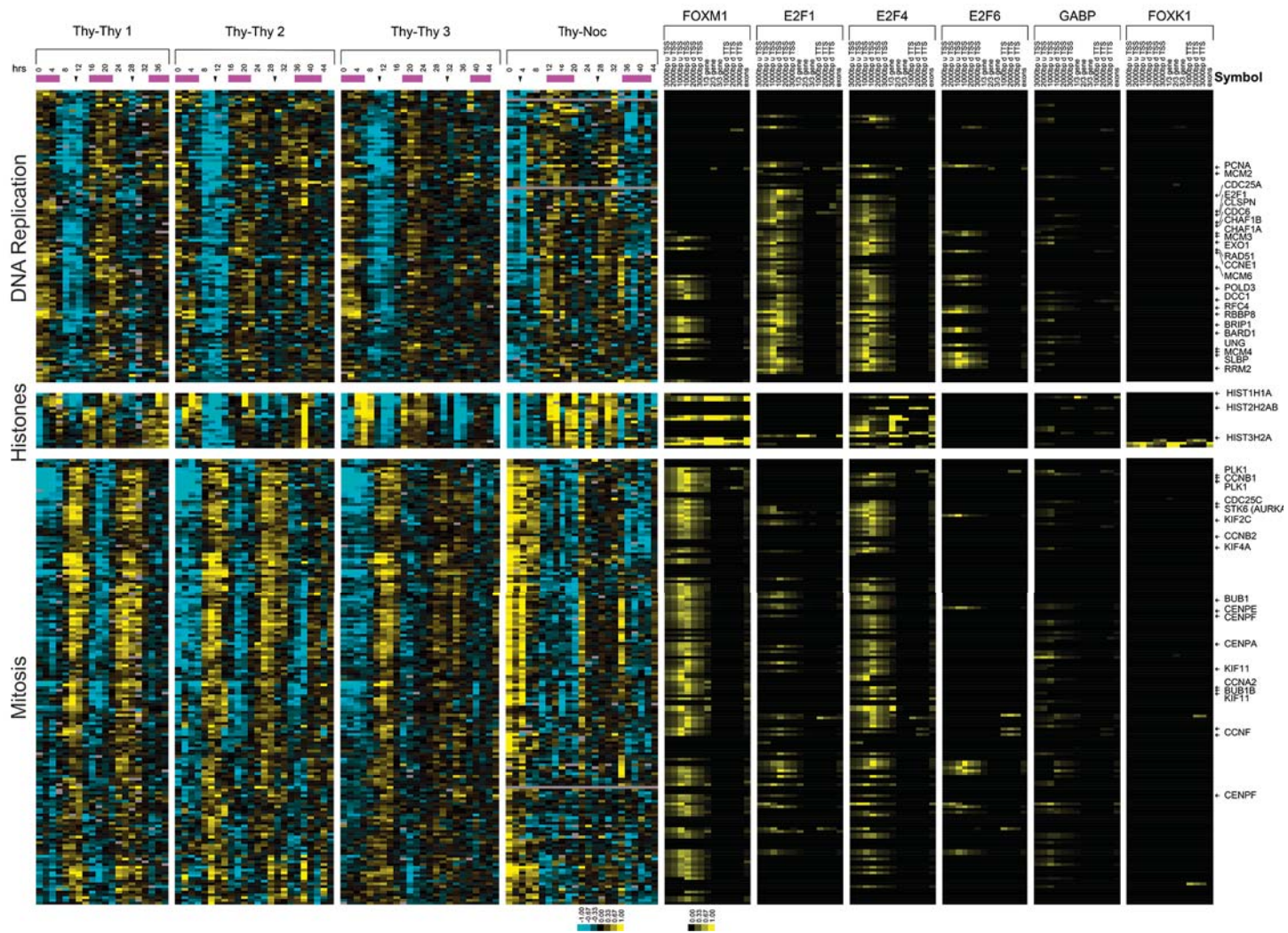
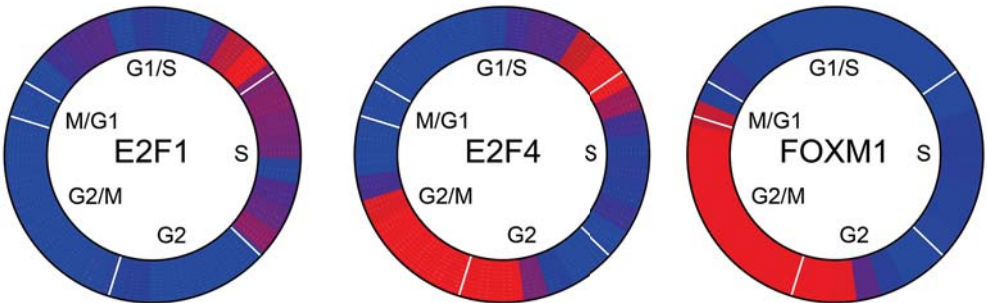
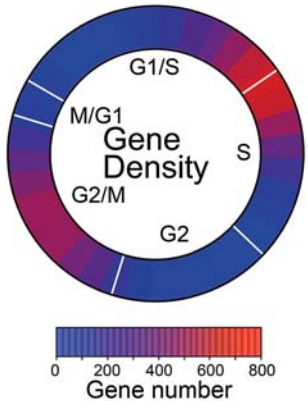


Figure 7

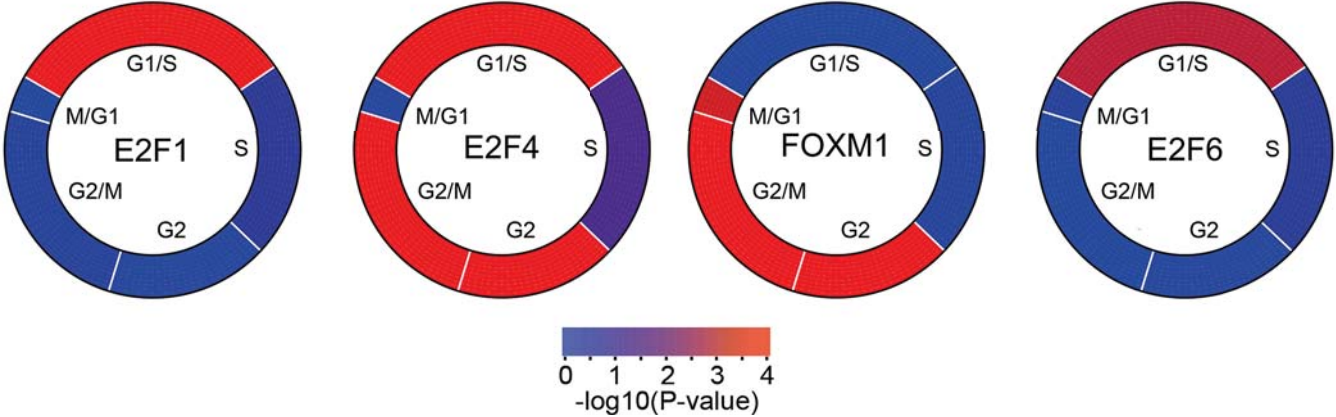
A.



B.



C.



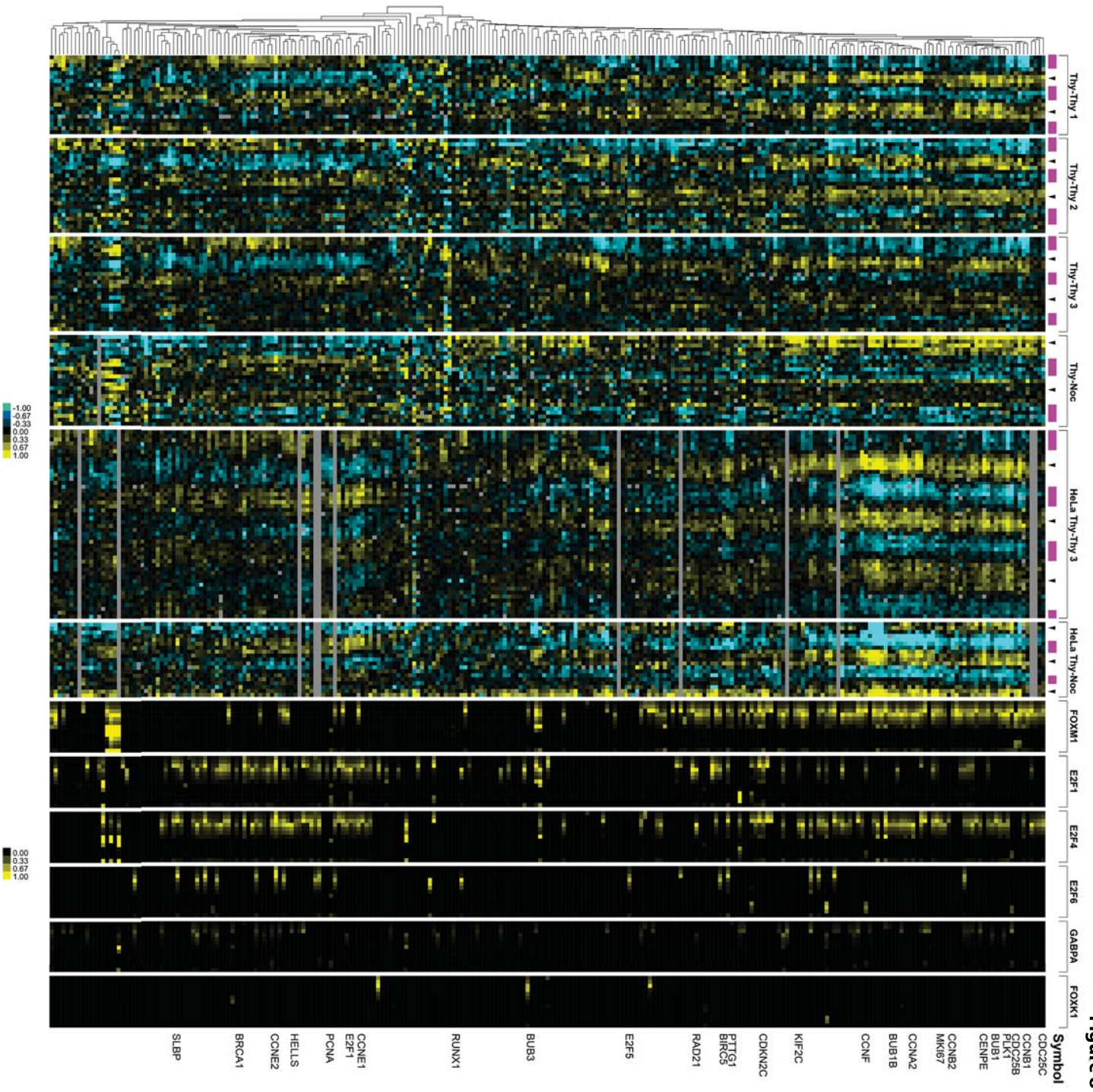


Figure 8

Supplemental Table 4: Previous identified FOXM1 target genes

| Symbol | Entrez GeneID | Citations |
|-----------------|----------------------|--|
| NFκB-p65 (RELA) | 8970 | (Bao, Wang et al. 2011) |
| HMGB2 | 3148 | (Huynh, Soh et al. 2011) |
| BORA | 79866 | (Alvarez-Fernandez, Halim et al. 2010) |
| CCNF | 899 | (reviewed in (Wierstra and Alves 2007)) |
| PRC1 | 9055 | (Huynh, Soh et al. 2011) |
| TOPO 2α (TOP2A) | 7153 | (Wang, Meliton et al. 2009) |
| DTL | 51514 | (Anders, Ke et al. 2011) |
| CCNG2 | 901 | (Anders, Ke et al. 2011) |
| AURKA | 6790 | (Calvisi, Pinna et al. 2009; Lefebvre, Rajbhandari et al. 2010; Mencialha, Binato et al. 2012; Raghavan, Zhou et al. 2012; Sadasivam, Duan et al. 2012) |
| HJURP | 55355 | (Huynh, Soh et al. 2011) |
| KIF20A | 10112 | (reviewed in (Wierstra and Alves 2007)) (Davis, Lavine et al. 2010) |
| CDC20 | 991 | (reviewed in (Wierstra and Alves 2007)) |
| PLK1 | 5347 | (reviewed in (Wierstra and Alves 2007)) (Fu, Malureanu et al. 2008; Chen, Dominguez-Brauer et al. 2009; Alvarez-Fernandez, Halim et al. 2010; Davis, Lavine et al. 2010; Anders, Ke et al. 2011; Chen, Yang et al. 2012; Ho, Wang et al. 2012; Sadasivam, Duan et al. 2012) |
| CCNB1 | 891 | (reviewed in (Wierstra and Alves 2007)) (Fu, Malureanu et al. 2008; Laoukili, Alvarez et al. 2008; Park, Kim et al. 2008; Xia, Huang et al. 2009; Alvarez-Fernandez, Halim et al. 2010; Davis, Lavine et al. 2010; Nakamura, Hirano et al. 2010; Xue, Chiang et al. 2010; Chen, Yang et al. 2012; Mencialha, Binato et al. 2012; Sadasivam, Duan et al. 2012; Xue, Xiao et al. 2012) |
| CENPF | 1063 | (reviewed in (Wierstra and Alves 2007)) (Laoukili, Alvarez et al. 2008; Anders, Ke et al. 2011) |
| CDCA8 | 55143 | (Davis, Lavine et al. 2010; Bergamaschi, Christensen et al. 2011) |
| CENPA | 1058 | (reviewed in (Wierstra and Alves 2007)) (Chen, Dominguez-Brauer et al. 2009; Davis, Lavine et al. 2010; Zhou, Wang et al. 2010) |
| UBEC (UBE2C) | 11065 | (Huynh, Soh et al. 2011) |
| NUSAP1 | 51203 | (Huynh, Soh et al. 2011) |
| CDCA2 | 157313 | (Davis, Lavine et al. 2010) |
| KAP (CDKN3) | 1033 | (reviewed in (Wierstra and Alves 2007)) |
| CDC25C | 995 | (reviewed in (Wierstra and Alves 2007)) |
| NEK2 | 4751 | (reviewed in (Wierstra and Alves 2007)) (Laoukili, Kooistra et al. 2005; Calvisi, Pinna et al. 2009; Davis, Lavine et al. 2010) |
| CCNB2 | 9133 | (reviewed in (Wierstra and Alves 2007)) |
| SMC4L1 (SMC4) | 10051 | (Huynh, Soh et al. 2011) |
| E2F2 | 1870 | (Anders, Ke et al. 2011) |
| CEP55 | 55165 | (Gemenetzidis, Bose et al. 2009) |
| TYMS | 7298 | (Huynh, Soh et al. 2011) |
| Brip1 (BRIP1) | 83990 | (Monteiro, Khongkow et al. 2012) |
| RACGAP1 | 29127 | (Sadasivam, Duan et al. 2012) |

| | | |
|----------------------|--------|--|
| MCM3 | 4172 | (Lefebvre, Rajbhandari et al. 2010) |
| KIF22 | 3835 | (Huynh, Soh et al. 2011) |
| CENPE | 1062 | (Davis, Lavine et al. 2010) |
| H2AFZ | 3015 | (Huynh, Soh et al. 2011) |
| PTTG1 | 9232 | (Lefebvre, Rajbhandari et al. 2010) |
| CCNA2 | 890 | (Davis, Lavine et al. 2010) (reviewed in (Wierstra and Alves 2007)) |
| BUBR1 (BUB1B) | 701 | (Lefebvre, Rajbhandari et al. 2010; Wan, Yeung et al. 2012) |
| SOX4 | 6659 | (Wang, Zhang et al. 2010) |
| GMNN | 51053 | (Huynh, Soh et al. 2011) |
| POLD3 | 10714 | (Anders, Ke et al. 2011) |
| ANLN | 54443 | (Huynh, Soh et al. 2011) |
| AURKB | 9212 | (reviewed in (Wierstra and Alves 2007)) (Fu, Malureanu et al. 2008; Park, Wang et al. 2008; Chen, Dominguez-Brauer et al. 2009; Davis, Lavine et al. 2010; Nakamura, Hirano et al. 2010; Zhou, Wang et al. 2010; Bergamaschi, Christensen et al. 2011; Wang and Gartel 2011; Bonet, Giuliano et al. 2012; Sadasivam, Duan et al. 2012) |
| BIRC5 | 332 | (reviewed in (Wierstra and Alves 2007)) (Chen, Dominguez-Brauer et al. 2009; Dai, Pieper et al. 2010; Nakamura, Hirano et al. 2010; Ahmad, Ali et al. 2011; Bergamaschi, Christensen et al. 2011; Chen, Yang et al. 2012; Down, Millour et al. 2012) |
| PRDX3 | 10935 | (Park, Carr et al. 2009) |
| Hsp70 (HSPA1A) | 3303 | (reviewed in (Wierstra and Alves 2007)) |
| PPIL5 (LRR1) | 122769 | (Anders, Ke et al. 2011) |
| CDC25B | 994 | (reviewed in (Wierstra and Alves 2007)) (Kalin, Wang et al. 2008; Nakamura, Hirano et al. 2010; Zhou, Wang et al. 2010; Bergamaschi, Christensen et al. 2011; Wang and Gartel 2011; Ho, Wang et al. 2012; Mencialha, Binato et al. 2012) |
| PHF19 | 26147 | (Huynh, Soh et al. 2011) |
| CHK1 (CHEK1) | 1111 | (Tan, Chen et al. 2010) |
| PCNA | 5111 | (Davis, Lavine et al. 2010; Bergamaschi, Christensen et al. 2011) |
| ELF3 | 1999 | (Ustiyana, Wert et al. 2012) |
| p27KIP1 (CDKN1B) | 1027 | (reviewed in (Wierstra and Alves 2007)) (Zeng, Wang et al. 2009; Nakamura, Hirano et al. 2010; Xue, Chiang et al. 2010; Xue, Xiao et al. 2012; Zhang, Zeng et al. 2012) |
| CENPB | 1059 | (reviewed in (Wierstra and Alves 2007)) (Zhou, Wang et al. 2010; Chen, Yang et al. 2012) |
| Skp2 | 6502 | (reviewed in (Wierstra and Alves 2007)) (Park, Wang et al. 2008; Calvisi, Pinna et al. 2009; Park, Kim et al. 2009; Nakamura, Hirano et al. 2010; Zhou, Wang et al. 2010; Ahmad, Ali et al. 2011; Anders, Ke et al. 2011; Chen, Yang et al. 2012; Ho, Wang et al. 2012; Mencialha, Binato et al. 2012; Zhang, Zeng et al. 2012) |
| BRCA2 | 675 | (reviewed in (Wierstra and Alves 2007)) (Alvarez-Fernandez, Halim et al. 2010) |
| XRCC1 | 7515 | (reviewed in (Wierstra and Alves 2007)) (Chetty, Bhoopathi et al. 2009) |
| ER α (ESR1) | 2099 | (reviewed in (Wierstra and Alves 2007)) |
| E-cadherin (CDH1) | 999 | (reviewed in (Wierstra and Alves 2007)) (Zhou, Wang et al. 2010; Wierstra 2011) |
| VEGF (VEGFA) | 7422 | (Zhang, Zhang et al. 2008; Gemenetidis, Bose et al. 2009; Li, Zhang et al. 2009; Ahmad, Wang et al. 2010; Ahmad, Ali et al. 2011; Bao, Wang et al. 2011; Chen, Yuan et al. 2011; Park, Gusarova et al. 2011; Karadedou, Gomes et al. 2012; Lynch, Ferrer et al. 2012; Xue, Xiao et al. 2012) |

| | | |
|---------------------|--------|---|
| KIS (UHMK1) | 127933 | (Petrovic, Costa et al. 2008; Nakamura, Hirano et al. 2010) |
| uPAR (PLAUR) | 5329 | (Ahmad, Wang et al. 2010; Lok, Chan et al. 2011; Li, Wei et al. 2012) |
| NEDD4-1 (NEDD4) | 4734 | (Dai, Pieper et al. 2010; Kwak, Wang et al. 2012) |
| Stathmin (STMN1) | 3925 | (Carr, Park et al. 2010; Park, Gusarova et al. 2011) |
| CDC25A | 993 | (reviewed in (Wierstra and Alves 2007)) |

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- Ahmad, A., Z. Wang, et al. (2010). "FoxM1 down-regulation leads to inhibition of proliferation, migration and invasion of breast cancer cells through the modulation of extra-cellular matrix degrading factors." Breast Cancer Res Treat **122**(2): 337-346.
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