# ChromHMM Tutorial

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# Talk Outline

- Chromatin states analysis and ChromHMM
- Accessing chromatin state annotations for ENCODE2 and Roadmap Epigenomics
- Running the ChromHMM software

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# Chromatin Marks for Genome Annotation

100+ histone modifications
Specificity in:

- Histone protein
- Amino acid residue
- Chemical modification (e.g. methyl, acetylation)
- Number of occurrence of the modifications

Examples
H3K4me1 – Enhancers
H3K4me3 – Promoters
H3K27me3 – Repressive
H3K9me3 – Repressive
H3K36me3 – Transcribed

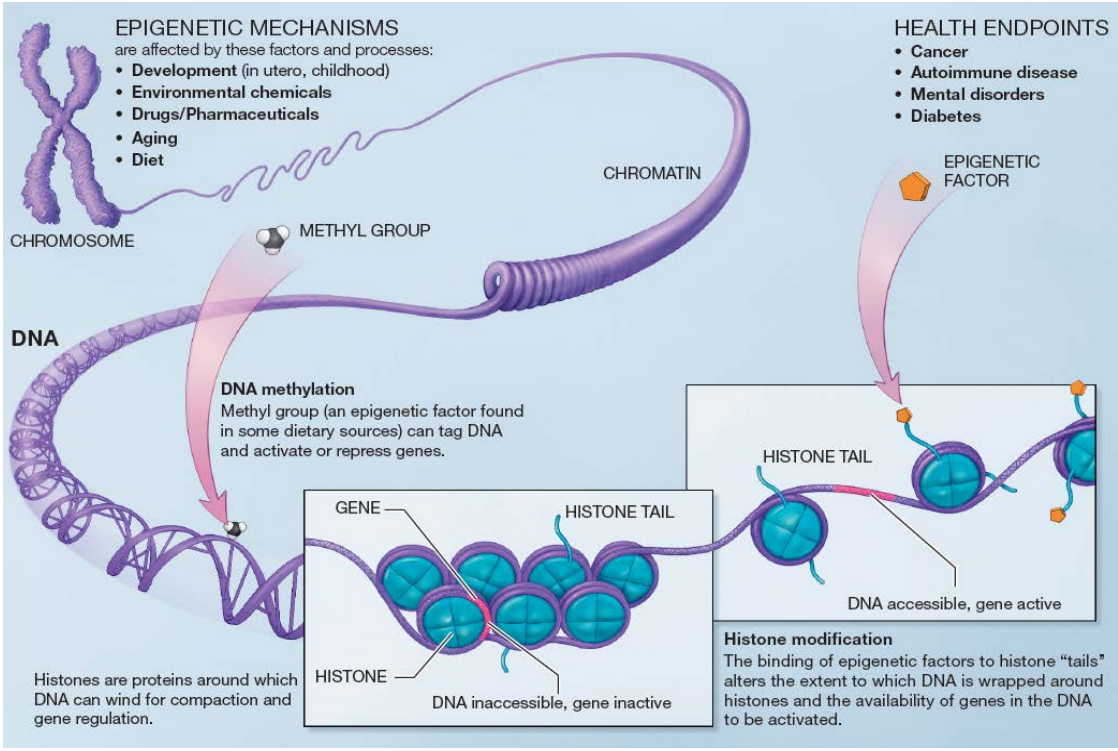
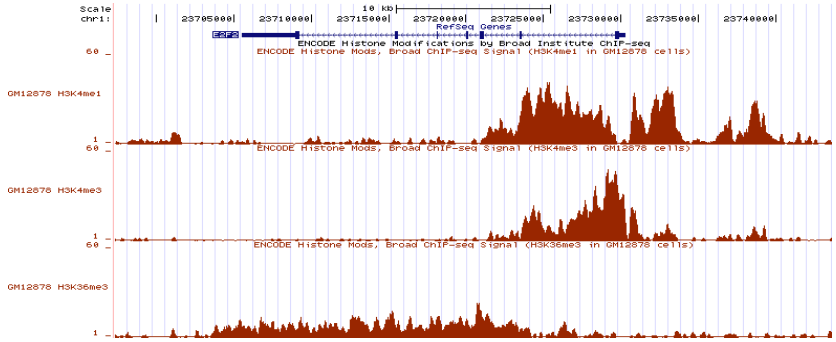
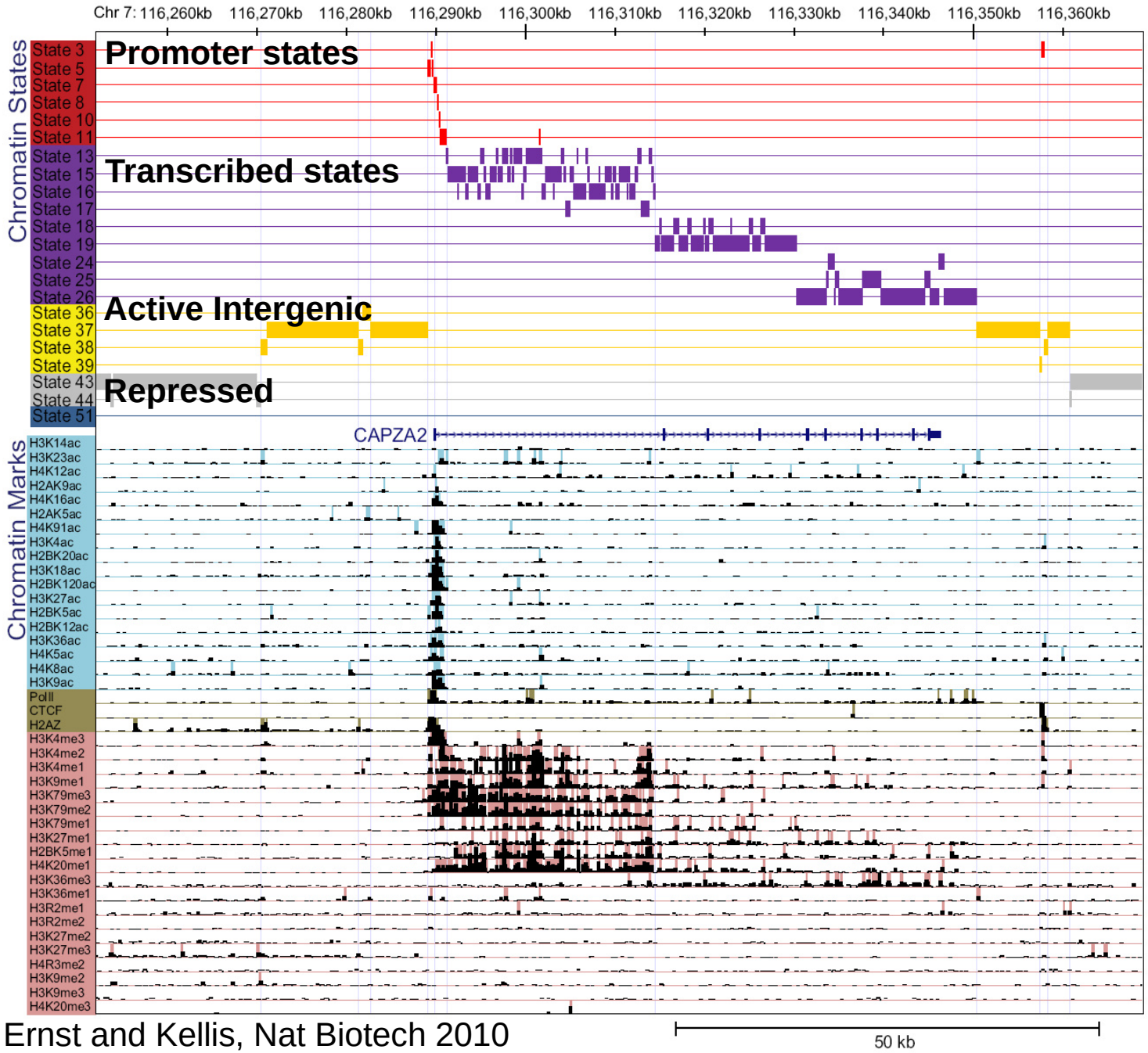



Image source: http://nihroadmap.nih.gov/epigenomics/

Histone Modifications can be Mapped Genome-wide with ChIP-seq



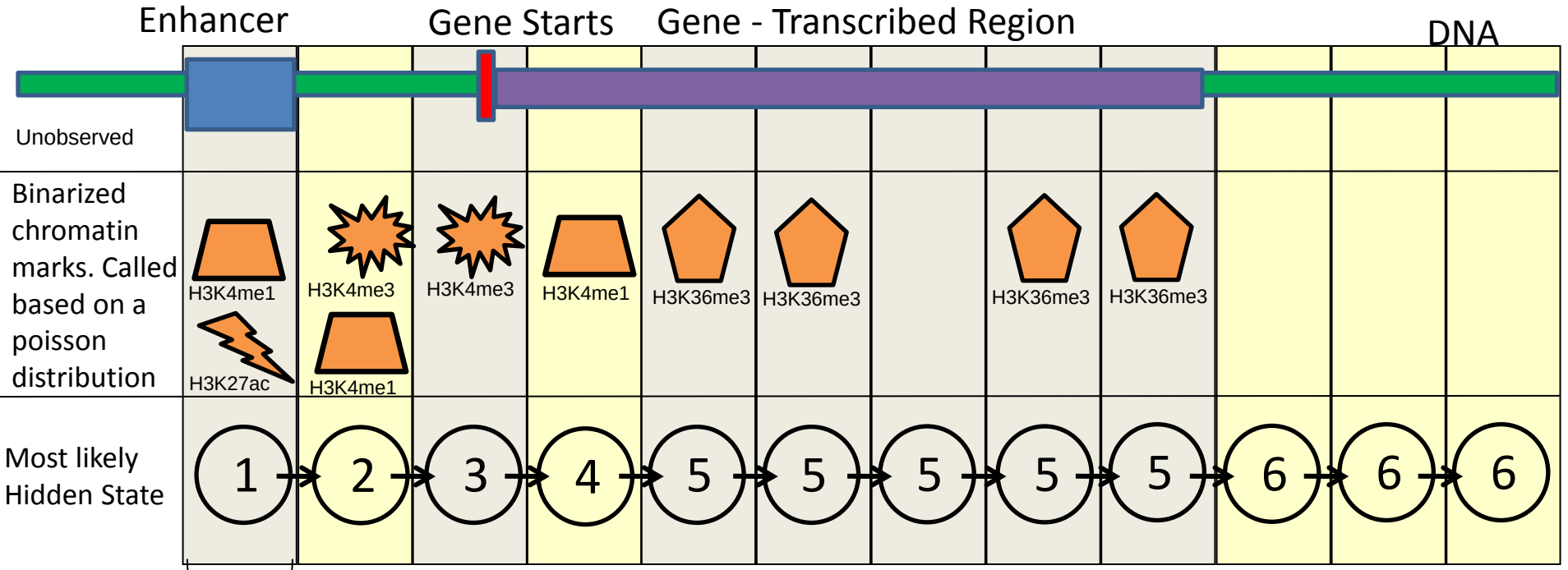
# From ‘chromatin marks’ to ‘chromatin states’



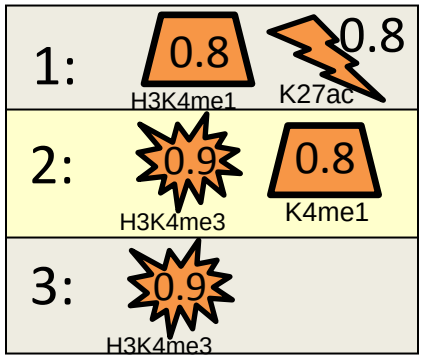

- Learn *de novo* significant combinational and spatial patterns of chromatin marks
- Use for genome annotation

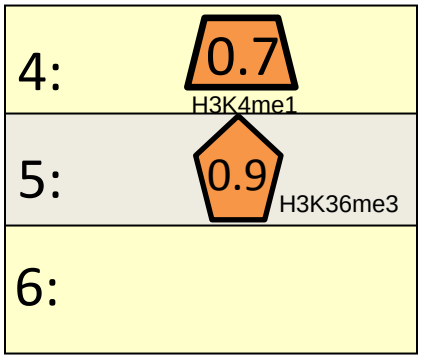
Ernst and Kellis, Nat Biotech 2010

# Approach: Multivariate Hidden Markov Model (ChromHMM)

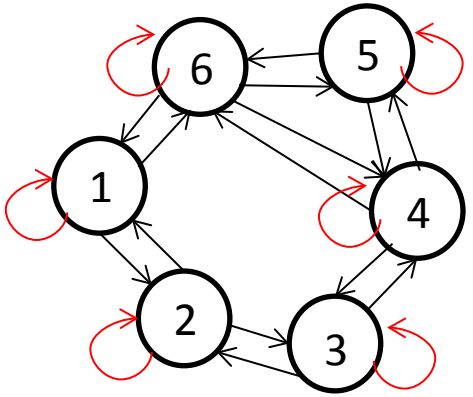



- Emission distribution is a product of independent Bernoulli random variables
- Parameters are learned from the data




Emission probabilities - High Probability Chromatin Marks in State




Transition probabilities
Red high probability
Black medium probability

Ernst and Kellis, Nat Biotech 2010 ; Ernst and Kellis, Nature Methods 2012

# ENCODE: Study nine marks in nine human cell lines

## 9 marks

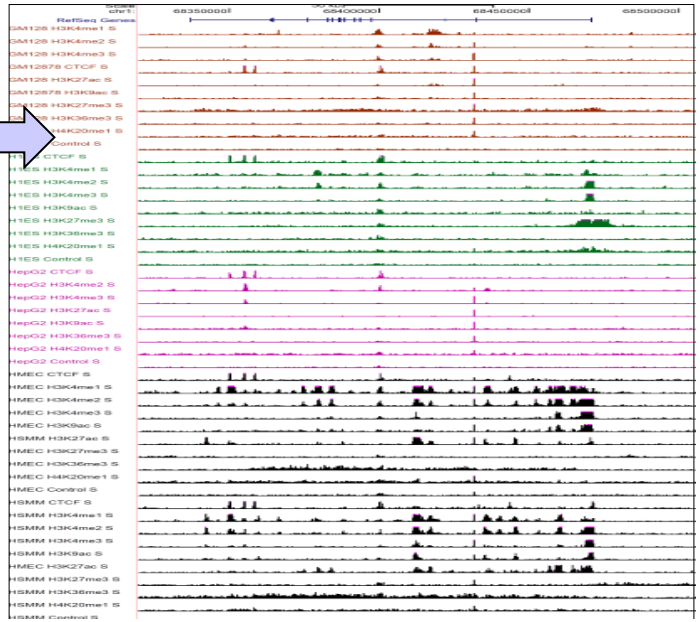
| |
|---|
| H3K4me1 |
| H3K4me2 |
| H3K4me3 |
| H3K27ac |
| H3K9ac |
| H3K27me3 |
| H4K20me1 |
| H3K36me3 |
| CTCF |
| +WCE |
| +RNA |

X

## 9 human cell types

| | |
|---|---|
| HUVEC | Umbilical vein endothelial |
| NHEK | Keratinocytes |
| GM12878 | Lymphoblastoid |
| K562 | Myelogenous leukemia |
| HepG2 | Liver carcinoma |
| NHLF | Normal human lung fibroblast |
| HMEC | Mammary epithelial cell |
| HSMM | Skeletal muscle myoblasts |
| H1 | Embryonic |

## 81 Chromatin Mark Tracks



**Brad Bernstein ENCODE Group**

HUVEC | NHEK | GM12878 | K562 | HepG2 | NHLF | HMEC | HSMM | H1

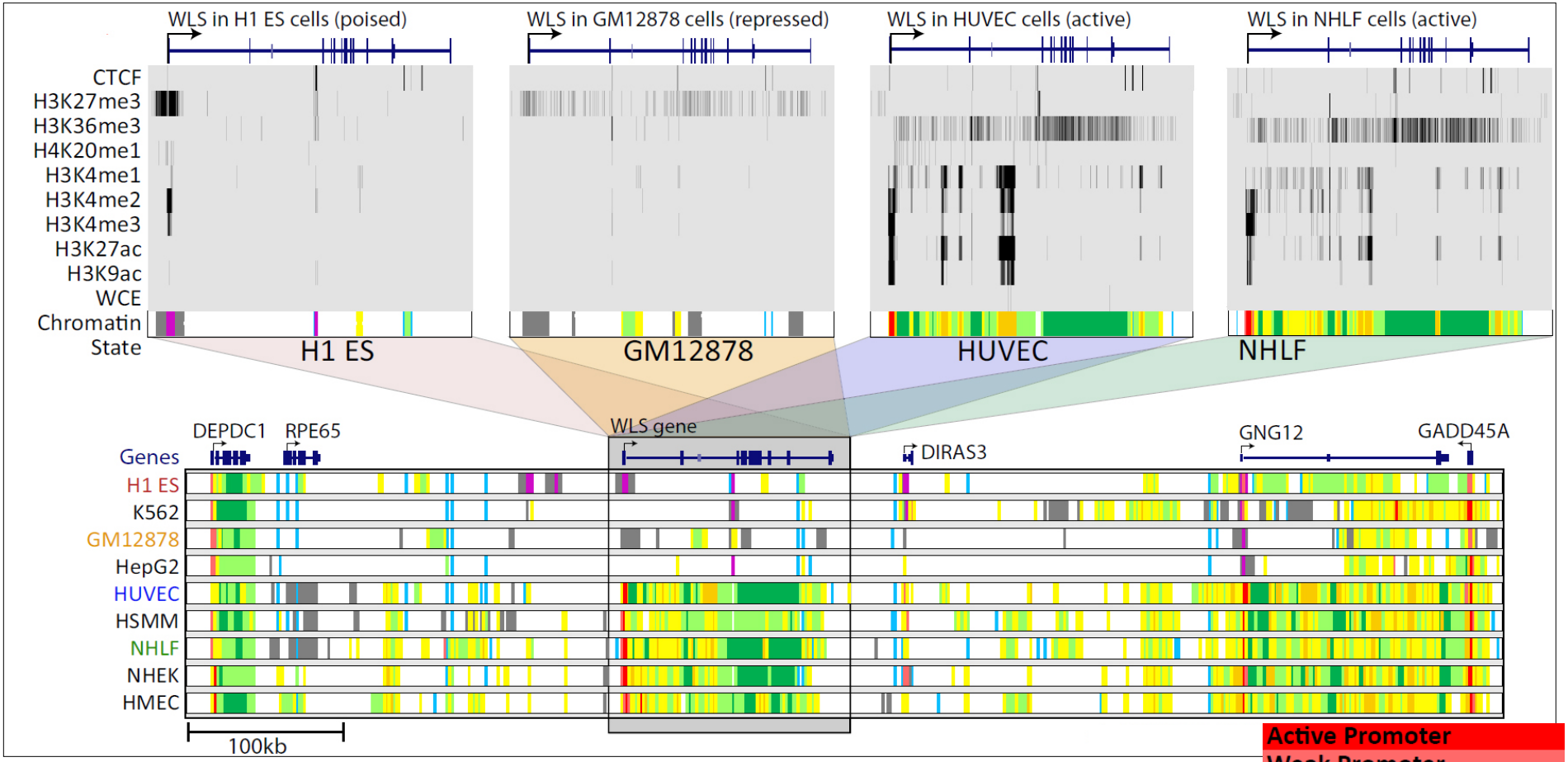
| State | CTCF | H3K27me3 | H3K36me3 | H4K20me1 | H3K4me1 | H3K4me2 | H3K4me3 | H3K27ac | H3K9ac | WCE | Coverage: Median | Coverage: H1 ES | Coverage: GM | Median Length | +/-2kb TSS | Conserved non-exon | DNase (K562) | C-Myc (K562) | NF-κB (GM12878) | Transcript | Nuclear Lamina (NHLF) | Candidate state annotation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 2 | 2 | 6 | 17 | 93 | 99 | 96 | 98 | 2 | 0.6 | 0.5 | 1.2 | 1.0 | 83 | 3.8 | 23.3 | 82.0 | 40.7 | 0.2 | 0.15 | Active Promoter |
| 2 | 12 | 2 | 6 | 9 | 53 | 94 | 95 | 14 | 44 | 1 | 0.5 | 1.2 | 1.3 | 0.4 | 58 | 2.8 | 15.3 | 12.6 | 5.8 | 0.6 | 0.30 | Weak Promoter |
| 3 | 13 | 72 | 0 | 9 | 48 | 78 | 49 | 1 | 10 | 1 | 0.2 | 4.0 | 1.0 | 0.6 | 49 | 4.3 | 10.8 | 3.1 | 1.0 | 0.4 | 0.68 | Inactive/poised Promoter |
| 4 | 11 | 1 | 15 | 11 | 96 | 99 | 75 | 97 | 86 | 4 | 0.7 | 0.1 | 1.1 | 0.6 | 23 | 2.7 | 23.1 | 31.8 | 49.0 | 1.3 | 0.05 | Strong enhancer |
| 5 | 5 | 0 | 10 | 3 | 88 | 57 | 5 | 84 | 25 | 1 | 1.2 | 0.2 | 0.7 | 0.6 | 3 | 1.8 | 13.6 | 6.3 | 15.8 | 1.4 | 0.10 | Strong enhancer |
| 6 | 7 | 1 | 1 | 3 | 58 | 75 | 8 | 6 | 5 | 1 | 0.9 | 1.3 | 1.0 | 0.2 | 17 | 2.4 | 11.9 | 5.7 | 7.0 | 1.1 | 0.31 | Weak/poised enhancer |
| 7 | 2 | 1 | 2 | 1 | 56 | 3 | 0 | 6 | 2 | 1 | 1.9 | 1.2 | 1.1 | 0.4 | 4 | 1.5 | 5.1 | 0.6 | 2.4 | 1.3 | 0.20 | Weak/poised enhancer |
| 8 | 92 | 2 | 1 | 3 | 6 | 3 | 0 | 0 | 1 | 1 | 0.5 | 1.4 | 1.0 | 0.4 | 3 | 1.5 | 12.8 | 2.5 | 1.2 | 1.1 | 0.61 | Insulator |
| 9 | 5 | 0 | 43 | 43 | 37 | 11 | 2 | 9 | 4 | 1 | 0.7 | 1.3 | 1.0 | 0.8 | 4 | 1.1 | 4.5 | 0.7 | 0.8 | 2.4 | 0.02 | Transcriptional transition |
| 10 | 1 | 0 | 47 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 4.3 | 0.6 | 1.2 | 3.0 | 1 | 0.9 | 0.3 | 0.0 | 0.0 | 2.5 | 0.11 | Transcriptional elongation |
| 11 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12.5 | 1.3 | 0.8 | 2.6 | 2 | 0.9 | 0.3 | 0.0 | 0.1 | 1.9 | 0.24 | Weak transcribed |
| 12 | 1 | 27 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4.1 | 0.3 | 0.7 | 2.8 | 5 | 1.4 | 0.3 | 0.0 | 0.1 | 0.8 | 0.63 | Polycomb-repressed |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71.4 | 1.0 | 1.0 | 10.0 | 1 | 0.9 | 0.1 | 0.0 | 0.0 | 0.7 | 1.30 | Heterochrom; low signal |
| 14 | 22 | 28 | 19 | 41 | 6 | 5 | 26 | 5 | 13 | 37 | 0.1 | 0.9 | 1.2 | 0.6 | 3 | 0.4 | 1.9 | 0.3 | 0.2 | 0.4 | 1.44 | Repetitive/CNV |
| 15 | 85 | 85 | 91 | 88 | 76 | 77 | 91 | 73 | 85 | 78 | 0.1 | 0.9 | 1.0 | 0.2 | 1 | 0.2 | 5.9 | 9.5 | 7.4 | 0.4 | 1.30 | Repetitive/CNV |

Chromatin States

Chromatin Mark Observation Frequency (%)

(%) (fold) (kb) (%) Functional enrichments (fold)

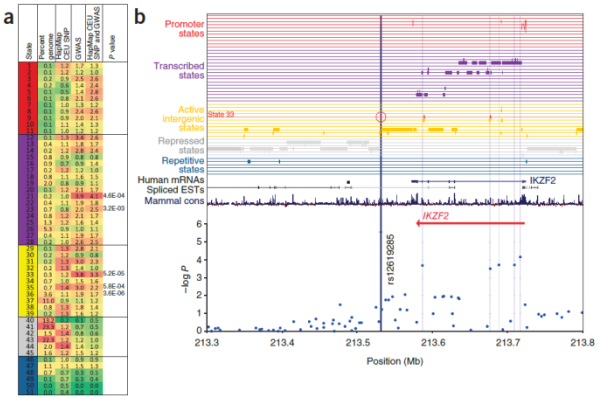
# Chromatin states dynamics across nine ENCODE cell types




- **Single annotation track for each cell type**
- **Summarize cell-type activity at a glance**
- **Can study 9-cell activity pattern across ↓**

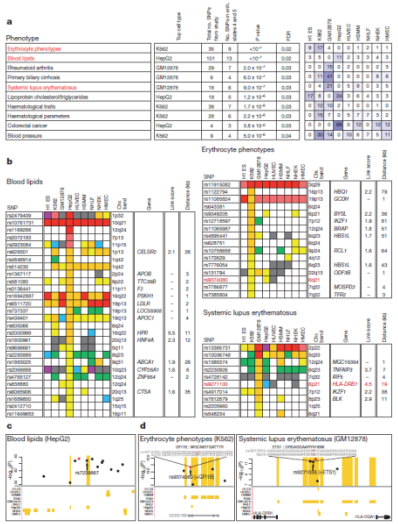
Ernst et al, *Nature* 2011

# Chromatin states to interpret disease variants



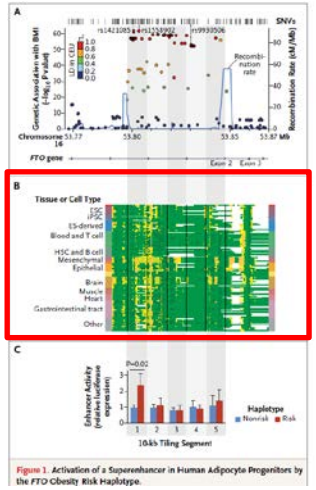

- Specific chromatin states enriched in GWAS catalog

Ernst and Kellis, *Nature Biotech* 2010



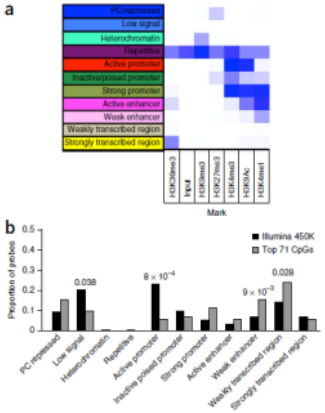

- Enhancers from different cell types enriched in different traits

Ernst et al, *Nature* 2011




- Imputation based chromatin state used in dissection FTO loci

Claussnitzer et al, *NEJM* 2015




- Interpreting epigenetic disease associated variation in Alzheimer's disease

De Jager et al, *Nature Neuroscience* 2014

- Many other examples in the literature

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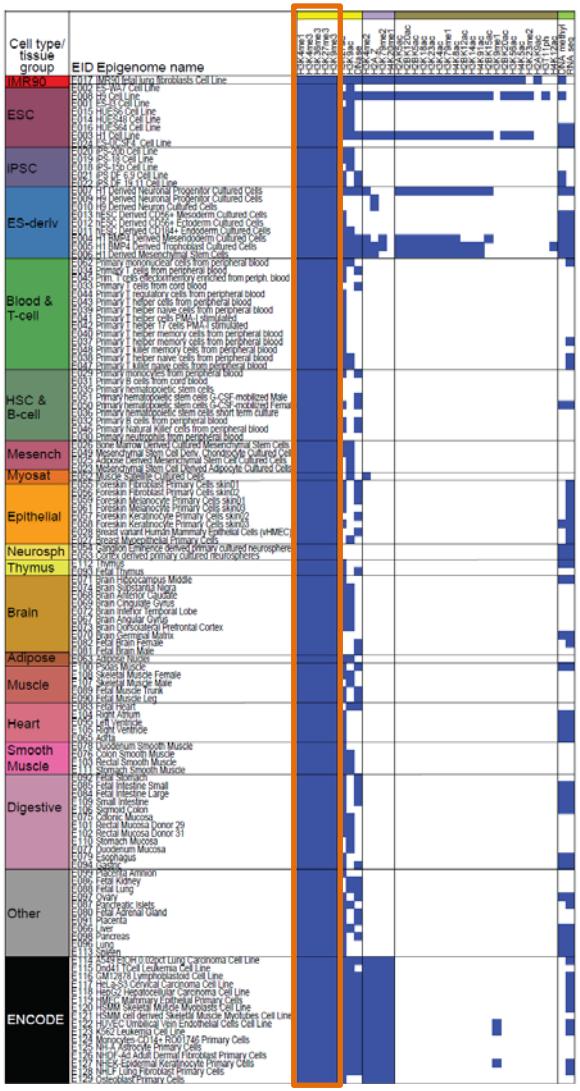
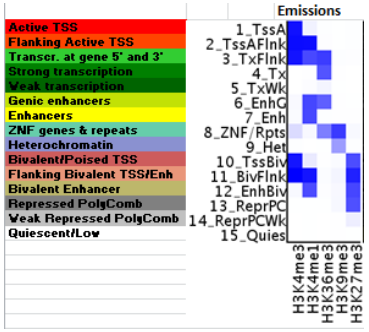
- Running the ChromHMM software

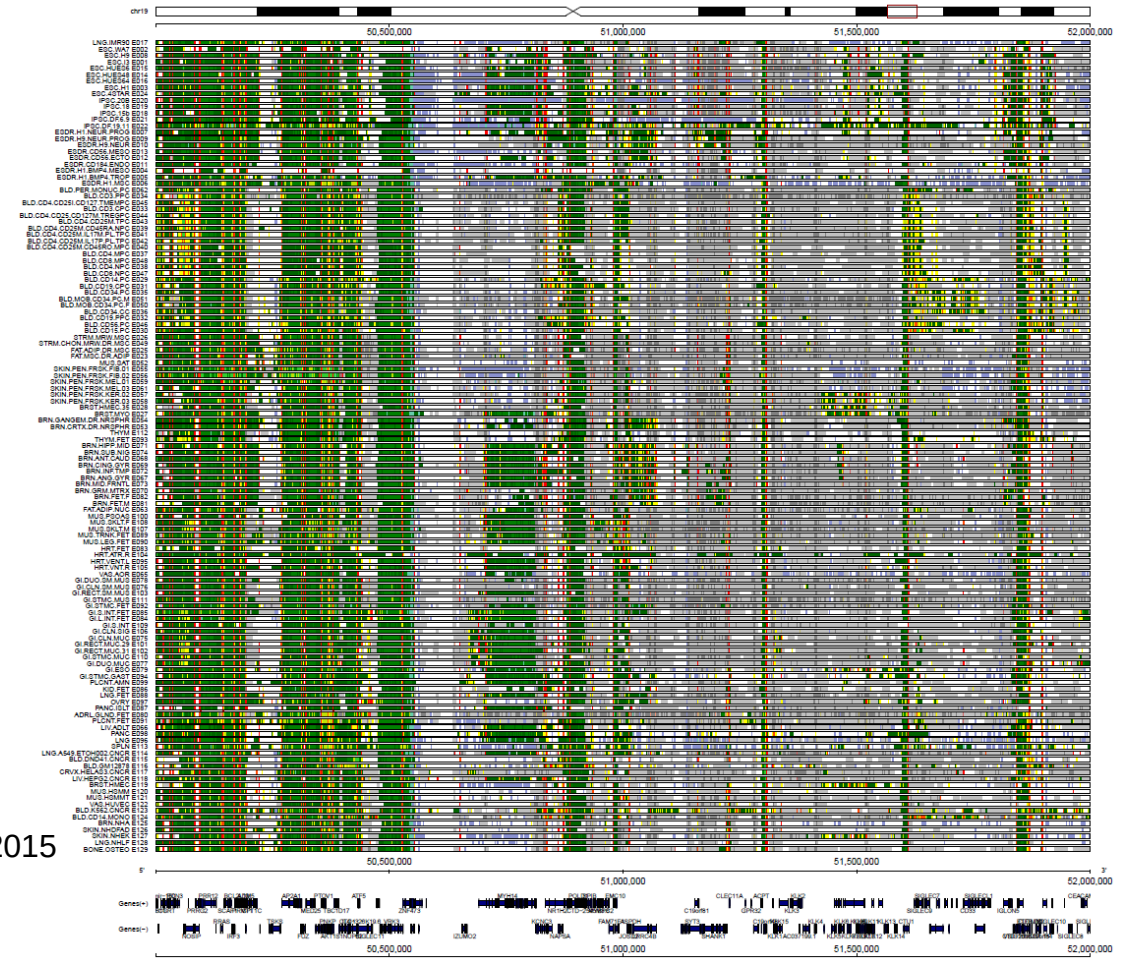
# Chromatin States Defined Across 127 Cell/Tissues Types




Observed



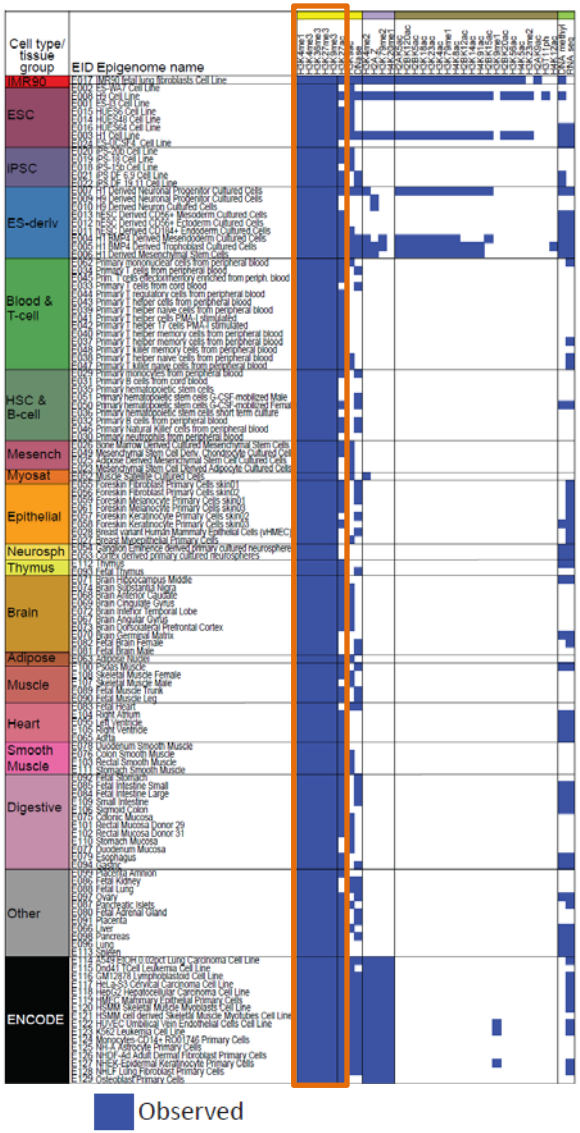

5 marks observed data



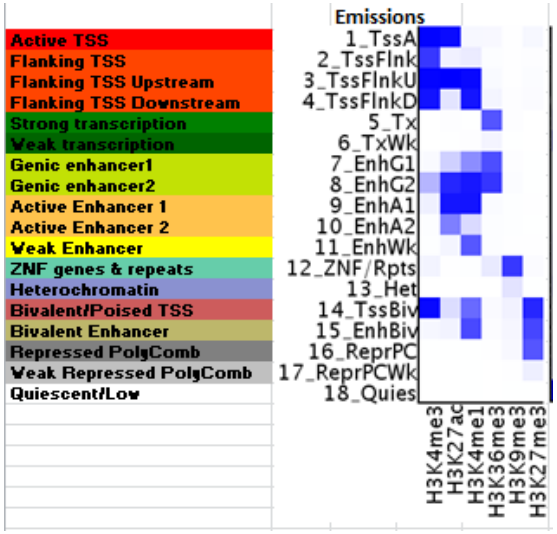

Roadmap Epigenomics Consortium et al, *Nature* 2015

16 cell types from ENCODE2

# Extended Chromatin State Model with H3K27ac



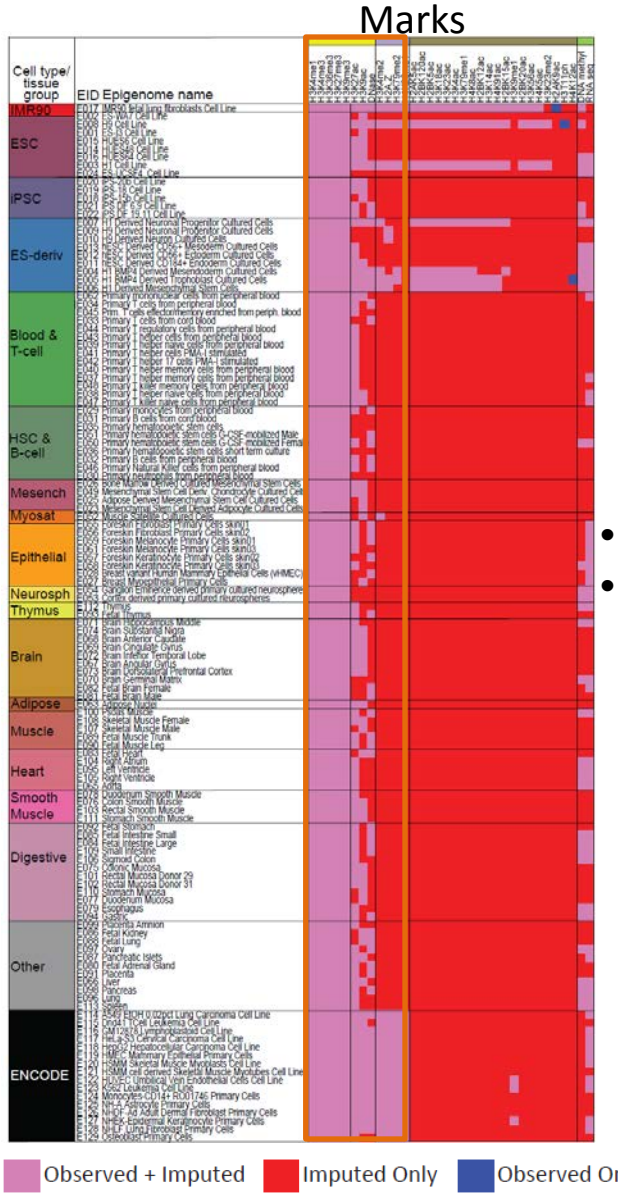

16 cell types from ENCODE2



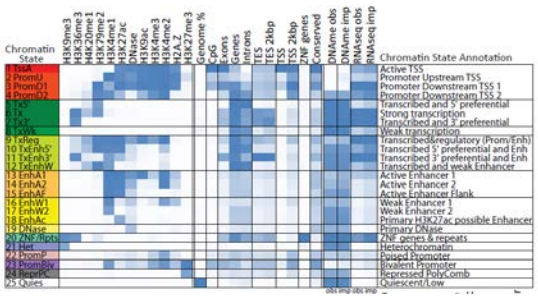

- 6 marks observed data
- Defined on 98 cell/tissue types only

Roadmap Epigenomics Consortium et al, *Nature* 2015

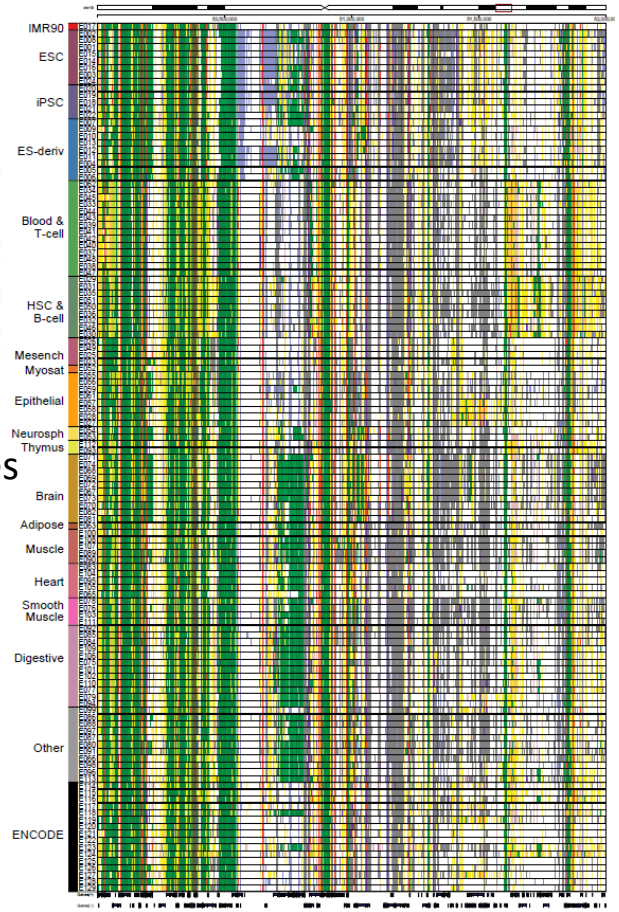
# Chromatin States Defined on Imputed Data




Ernst and Kellis, *Nature Biotech* 2015




- 12 marks imputed data
- Defined on all cell/tissue types




ChromImpute method

# ChromHMM Models across Many Roadmap/ENCODE2 Cell and Tissue Types

**Primary Core Marks segmentation**

- State 1 - Red - TssA (Active_TSS)
- State 2 - OrangeRed - TssAFlnk (Flanking_Active_TSS)
- State 3 - LimeGreen - TxFlnk (Transcr_at_gene_5_and_3primer)
- State 4 - Green - Tx (Strong_transcription)
- State 5 - DarkGreen - TxWk (Weak_transcription)
- State 6 - GreenYellow - EnhG (Genic_enhancers)
- State 7 - Yellow - Enh (Enhancers)
- State 8 - MediumAquamarine - ZNF/Rpts (ZNF_genes&repeats)
- State 9 - PaleTurquoise - Het (Heterochromatin)
- State 10 - IndianRed - TssBiv (Bivalent/Poised_TSS)
- State 11 - DarkSalmon - BivFlnk (Flanking_Bivalent_TSS/Enh)
- State 12 - DarkKhaki - EnhBiv (Bivalent_Enhancer)
- State 13 - Silver - ReprPC (Repressed_PolyComb)
- State 14 - Gainsboro - ReprPCWk (Weak_Repressed_PolyComb)
- State 15 - White - Quies (Quiescent/Low)

127 Cell/Tissue Types

H3K4me1
H3K4me3
H3K27me3
H3K9me3
H3K36me3

**Auxiliary Core Marks + K27ac segmentation**

- State 1 - Red - TssA (Active_TSS)
- State 2 - Orange_Red - TssFlnk (Flanking_TSS)
- State 3 - Orange_Red - TssFlnkU (Flanking_TSS_Upstream)
- State 4 - Orange_Red - TssFlnkD (Flanking_TSS_Downstream)
- State 5 - Green - Tx (Strong_transcription)
- State 6 - DarkGreen - TxWk (Weak_transcription)
- State 7 - GreenYellow - EnhG1 (Genic_enhancer1)
- State 8 - GreenYellow - EnhG2 (Genic_enhancer2)
- State 9 - Orange - EnhA1 (Active_Enhancer1)
- State 10 - Orange - EnhA2 (Active_Enhancer2)
- State 11 - Yellow - EnhWk (Weak_Enhancer)
- State 12 - Medium_Aquamarine - ZNF/Rpts (ZNF_genes&repeats)
- State 13 - PaleTurquoise - Het (Heterochromatin)
- State 14 - IndianRed - TssBiv (Bivalent/Poised_TSS)
- State 15 - DarkKhaki - EnhBiv (Bivalent_Enhancer)
- State 16 - Silver - ReprPC (Repressed_PolyComb)
- State 17 - Gainsboro - ReprPCWk (Weak_Repressed_PolyComb)
- State 18 - White - Quies (Quiescent/Low)

98 Cell/Tissue Types

H3K4me1
H3K4me3
H3K27me3
H3K9me3
H3K36me3
H3K27ac

**Imputed Marks Segmentation**

- State 1 - Red - TssA (Active TSS)
- State 2 - Orange Red - PromU (Promoter Upstream TSS)
- State 3 - Orange Red - PromD1 (Promoter Downstream TSS with DNase)
- State 4 - Orange Red - PromD2 (Promoter Downstream TSS)
- State 5 - Green - Tx5' (Transcription 5')
- State 6 - Green - Tx (Transcription)
- State 7 - Green - Tx3' (Transcription 3')
- State 8 - Light Green - TxWk (Weak transcription)
- State 9 - GreenYellow - TxReg (Transcription Regulatory)
- State 10 - GreenYellow - TxEnh5' (Transcription 5' Enhancer)
- State 11 - GreenYellow - TxEnh3' (Transcription 3' Enhancer)
- State 12 - GreenYellow - TxEnhW (Transcription Weak Enhancer)
- State 13 - Orange - EnhA1 (Active Enhancer 1)
- State 14 - Orange - EnhA2 (Active Enhancer 2)
- State 15 - Orange - EnhAF (Active Enhancer Flank)
- State 16 - Yellow - EnhW1 (Weak Enhancer 1)
- State 17 - Yellow - EnhW2 (Weak Enhancer 2)
- State 18 - Yellow - EnhAc (Enhancer Acetylation Only)
- State 19 - Light Yellow - DNase (DNase only)
- State 20 - Medium Aquamarine - ZNF/Rpts (ZNF genes & repeats)
- State 21 - PaleTurquoise - Het (Heterochromatin)
- State 22 - Light Purple - PromP (Poised Promoter)
- State 23 - Purple - PromBiv (Bivalent Promoter)
- State 24 - Silver - ReprPC (Repressed PolyComb)
- State 25 - White - Quies (Quiescent/Low)

127 Cell/Tissue Types

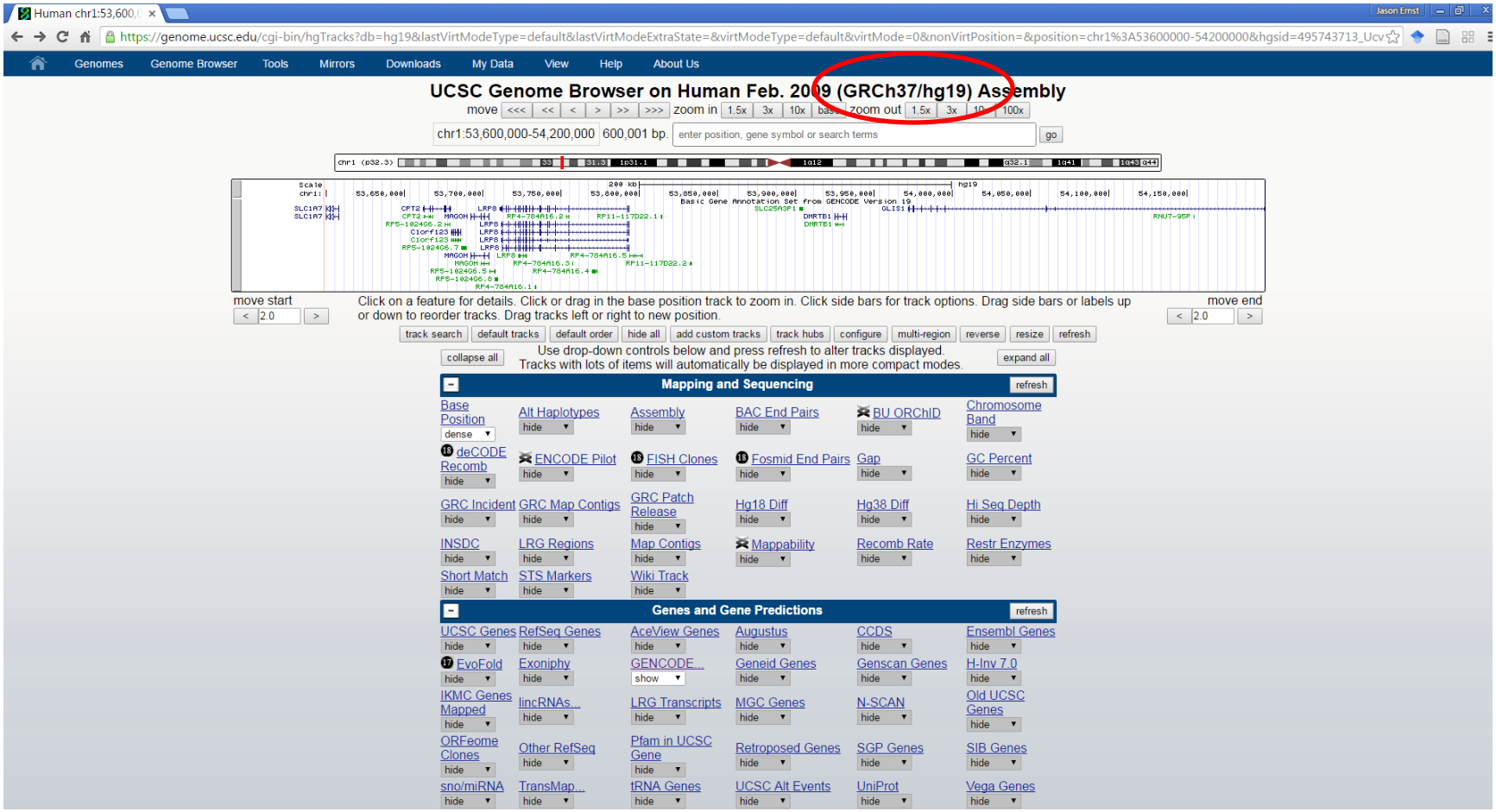
| | |
|---|---|
| H3K4me1 | H3K9ac |
| H3K4me3 | H4K20me1 |
| H3K27me3 | H3K79me2 |
| H3K9me3 | H3K4me2 |
| H3K36me3 | H2A.Z |
| H3K27ac | DNase |

Images from UCSC genome browser

Note: additional ChromHMM annotations based on older ENCODE models available from UCSC genome browser

# Accessing Roadmap/ENCODE2 ChromHMM through the UCSC Genome Browser Track Hubs

http://genome.ucsc.edu



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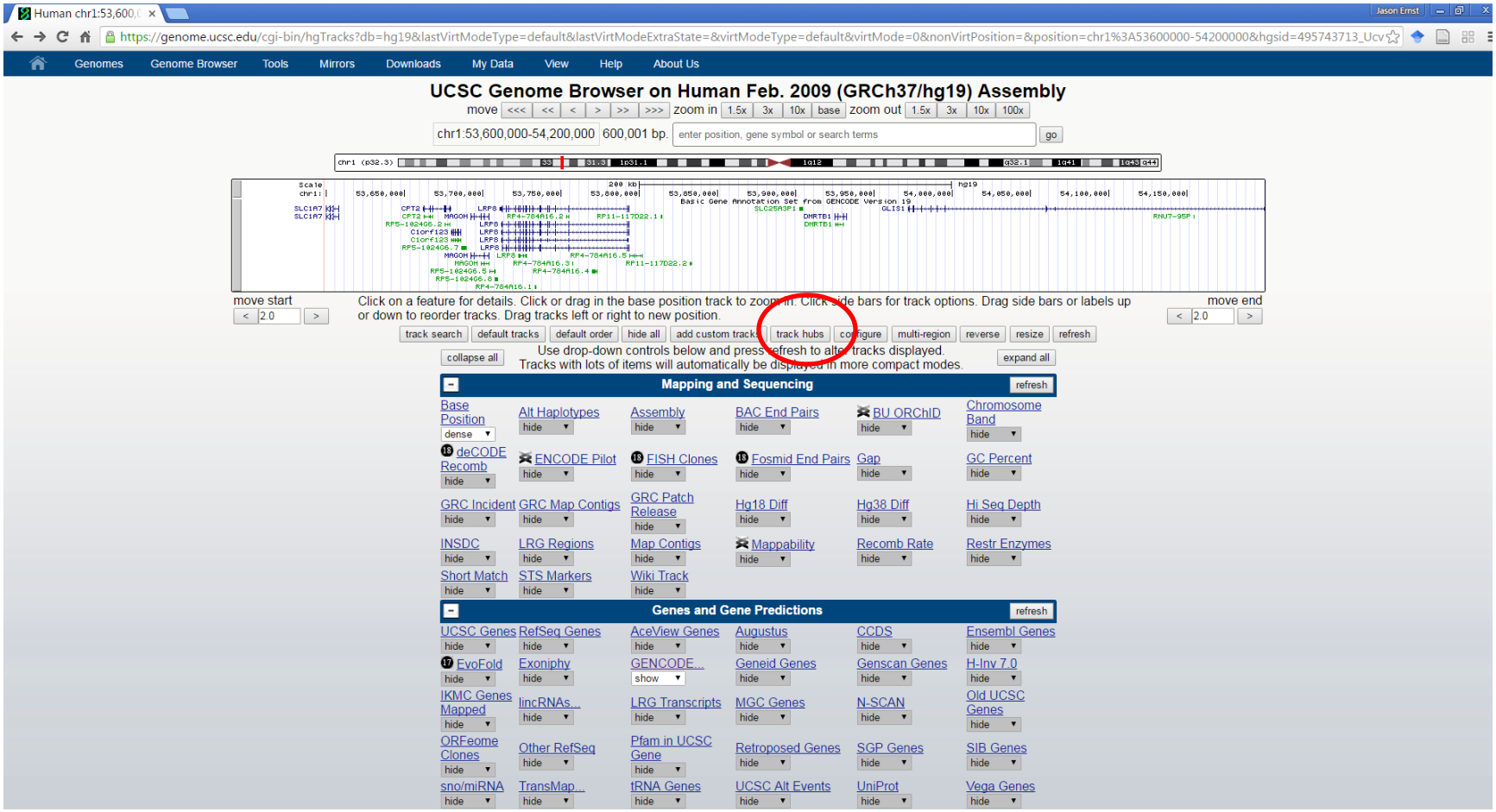

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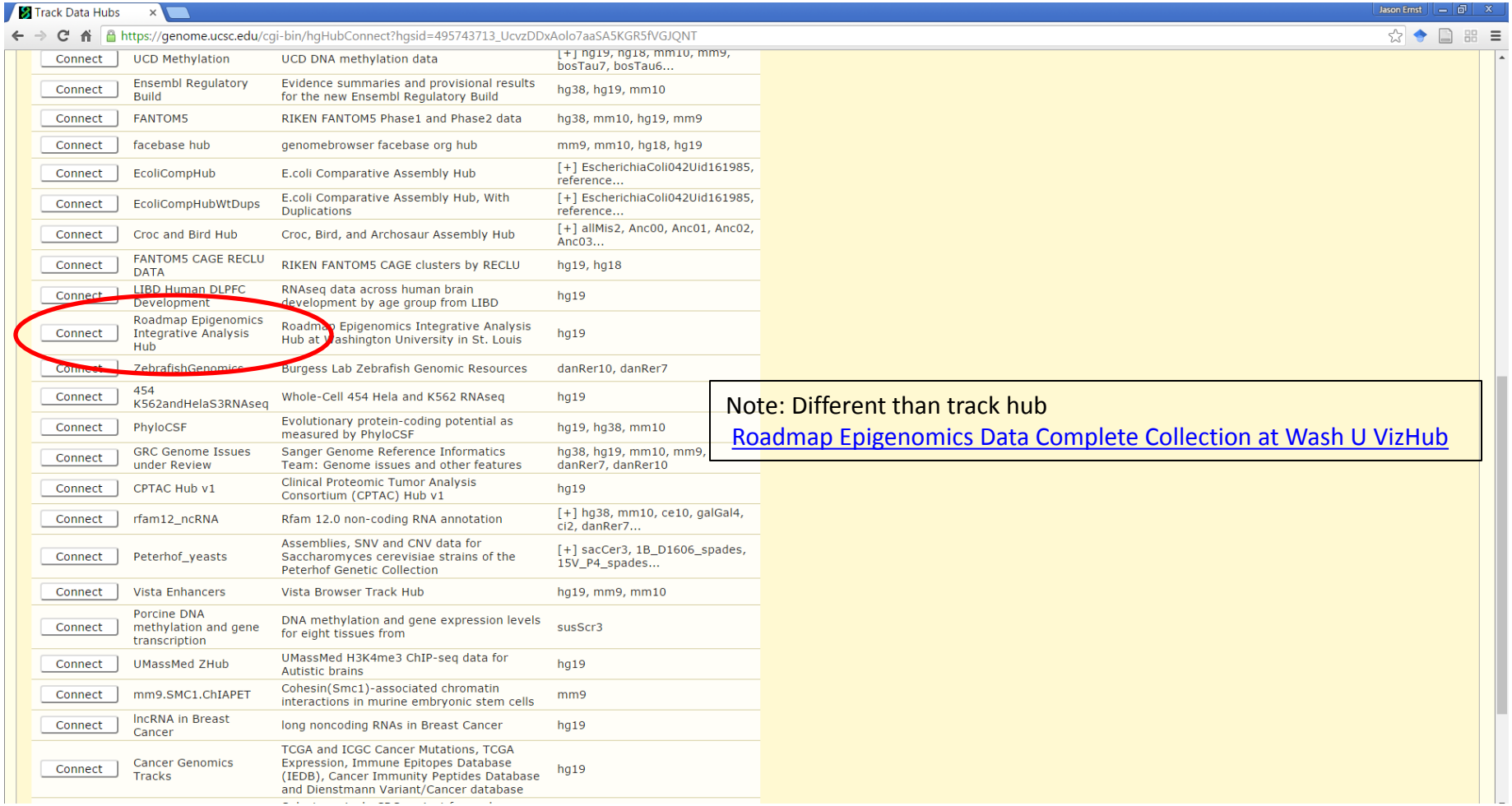


| | | | |
|---|---|---|---|
| Connect | UCD Methylation | UCD DNA methylation data | [+] hg19, hg18, mm10, mm9, bosTau7, bosTau6... |
| Connect | Ensembl Regulatory Build | Evidence summaries and provisional results for the new Ensembl Regulatory Build | hg38, hg19, mm10 |
| Connect | FANTOM5 | RIKEN FANTOM5 Phase1 and Phase2 data | hg38, mm10, hg19, mm9 |
| Connect | facebase hub | genomebrowser facebase org hub | mm9, mm10, hg18, hg19 |
| Connect | EcoliCompHub | E.coli Comparative Assembly Hub | [+] EscherichiaColi042Uid161985, reference... |
| Connect | EcoliCompHubWtDups | E.coli Comparative Assembly Hub, With Duplications | [+] EscherichiaColi042Uid161985, reference... |
| Connect | Croc and Bird Hub | Croc, Bird, and Archosaur Assembly Hub | [+] allMis2, Anc00, Anc01, Anc02, Anc03... |
| Connect | FANTOM5 CAGE RECLU DATA | RIKEN FANTOM5 CAGE clusters by RECLU | hg19, hg18 |
| Connect | LIBD Human DLPFC Development | RNAseq data across human brain development by age group from LIBD | hg19 |
| Connect | Roadmap Epigenomics Integrative Analysis Hub | Roadmap Epigenomics Integrative Analysis Hub at Washington University in St. Louis | hg19 |
| Connect | ZebrafishGenomics | Burgess Lab Zebrafish Genomic Resources | danRer10, danRer7 |
| Connect | 454 K562andHelaS3RNAseq | Whole-Cell 454 Hela and K562 RNAseq | hg19 |
| Connect | PhyloCSF | Evolutionary protein-coding potential as measured by PhyloCSF | hg19, hg38, mm10 |
| Connect | GRC Genome Issues under Review | Sanger Genome Reference Informatics Team: Genome issues and other features | hg38, hg19, mm10, mm9, danRer7, danRer10 |
| Connect | CPTAC Hub v1 | Clinical Proteomic Tumor Analysis Consortium (CPTAC) Hub v1 | hg19 |
| Connect | rfam12_ncRNA | Rfam 12.0 non-coding RNA annotation | [+] hg38, mm10, ce10, galGal4, ci2, danRer7... |
| Connect | Peterhof_yeasts | Assemblies, SNV and CNV data for Saccharomyces cerevisiae strains of the Peterhof Genetic Collection | [+] sacCer3, 1B_D1606_spades, 15V_P4_spades... |
| Connect | Vista Enhancers | Vista Browser Track Hub | hg19, mm9, mm10 |
| Connect | Porcine DNA methylation and gene transcription | DNA methylation and gene expression levels for eight tissues from | susScr3 |
| Connect | UMassMed ZHub | UMassMed H3K4me3 ChIP-seq data for Autistic brains | hg19 |
| Connect | mm9.SMC1.ChIAPET | Cohesin(Smc1)-associated chromatin interactions in murine embryonic stem cells | mm9 |
| Connect | lncRNA in Breast Cancer | long noncoding RNAs in Breast Cancer | hg19 |
| Connect | Cancer Genomics Tracks | TCGA and ICGC Cancer Mutations, TCGA Expression, Immune Epitopes Database (IEDB), Cancer Immunity Peptides Database and Dienstmann Variant/Cancer database | hg19 |

Note: Different than track hub
[Roadmap Epigenomics Data Complete Collection at Wash U VizHub]

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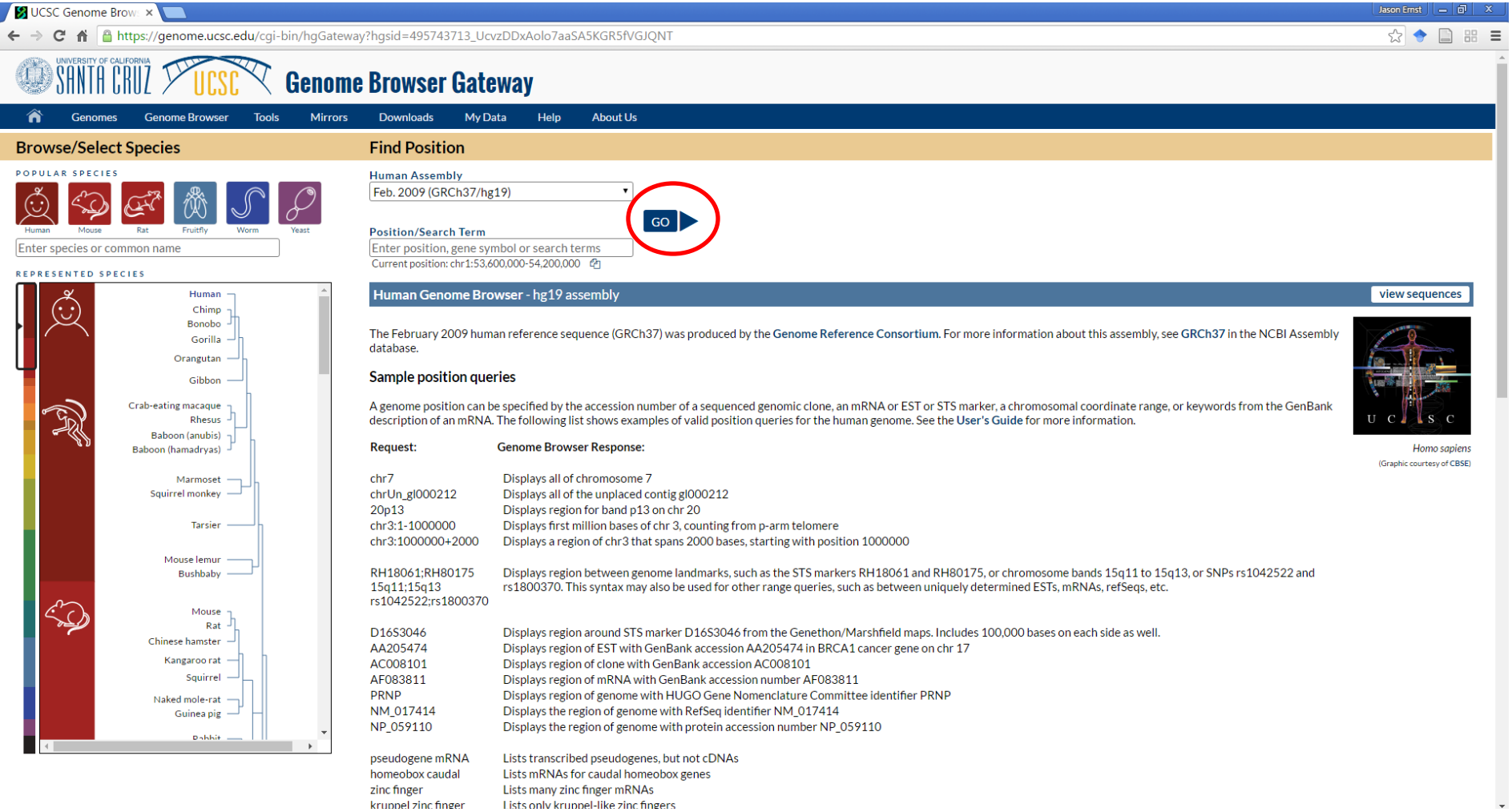
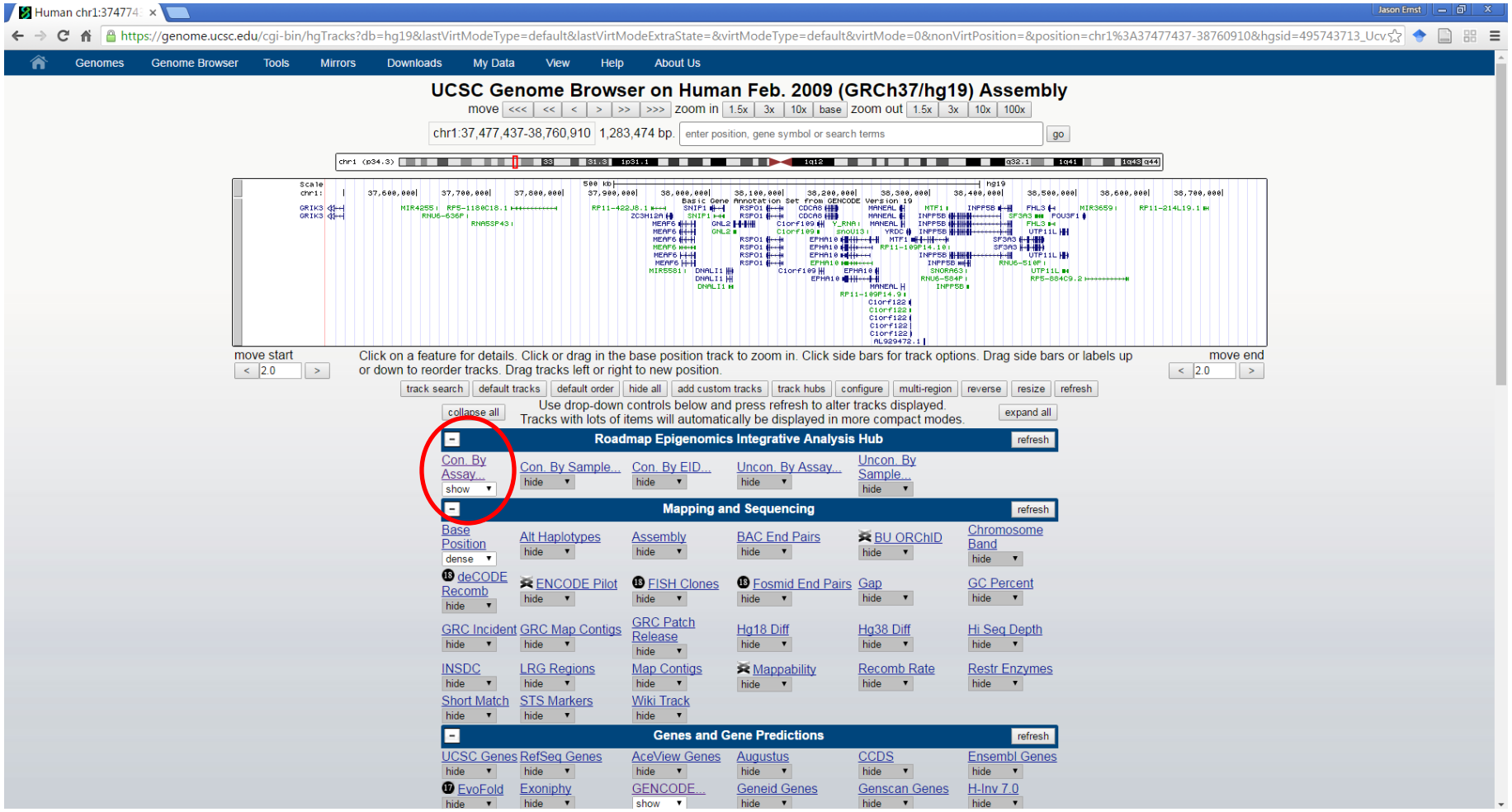


# Accessing Roadmap/ENCODE2 ChromHMM through the UCSC Genome Browser Track Hubs



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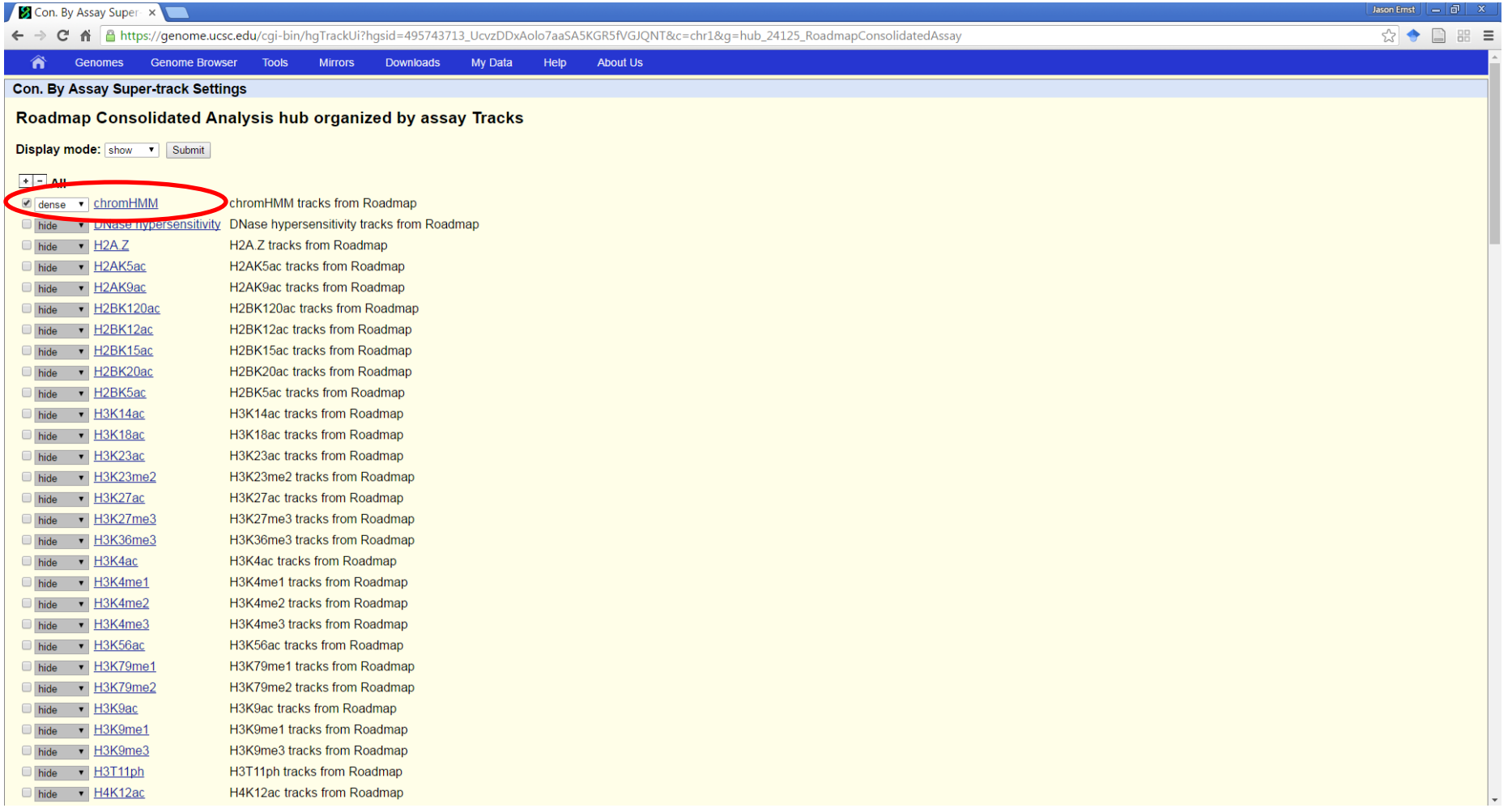

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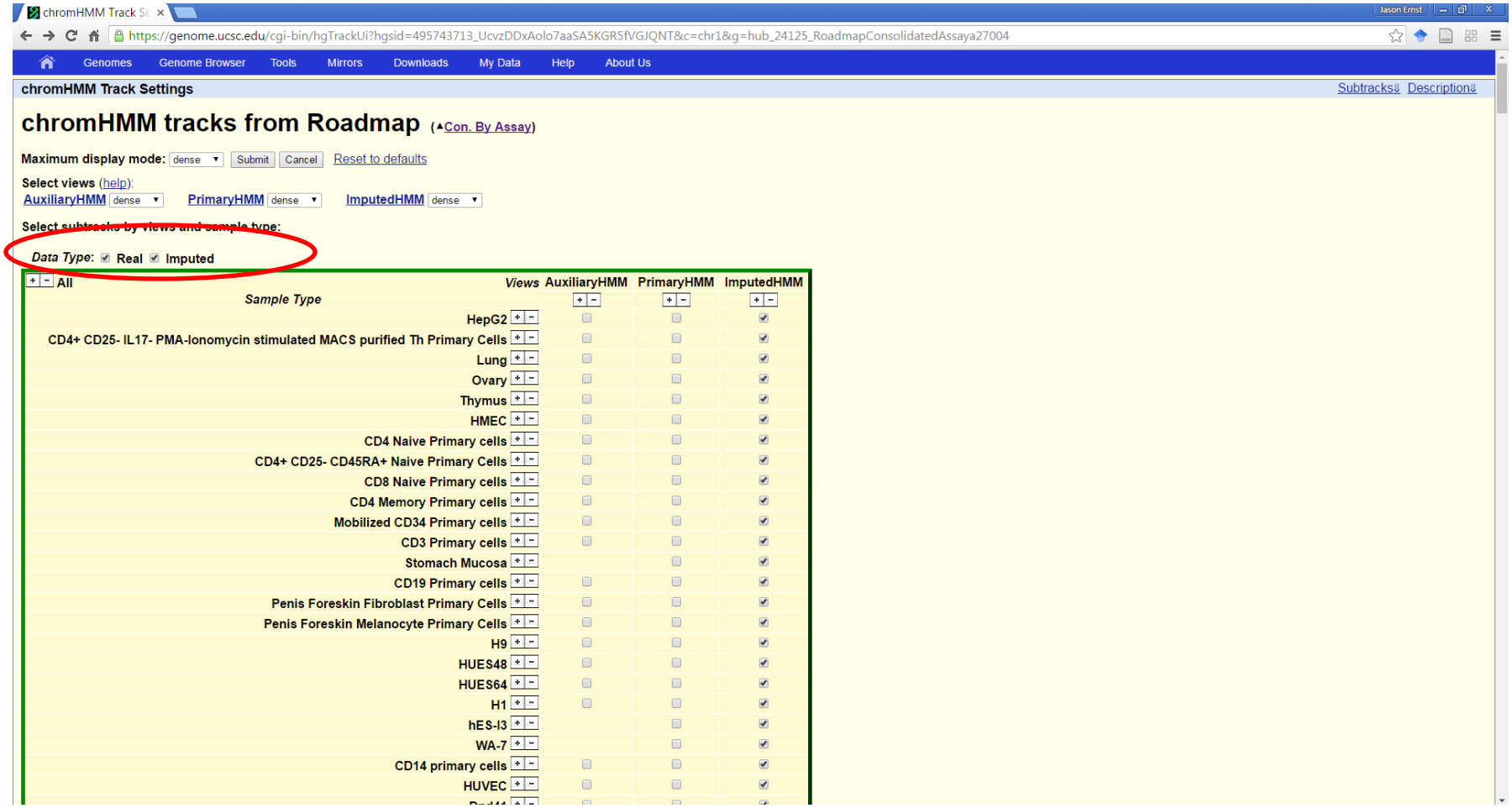

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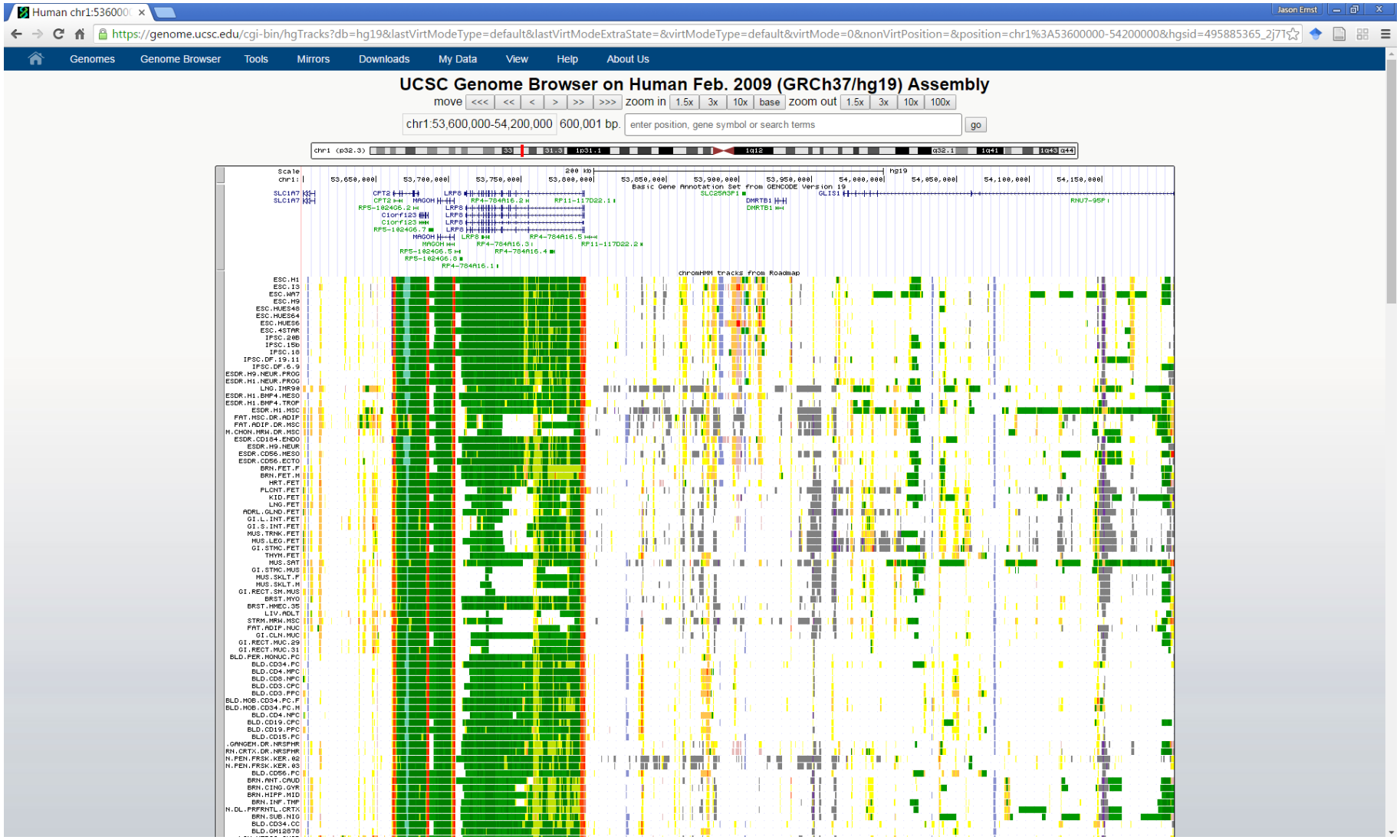
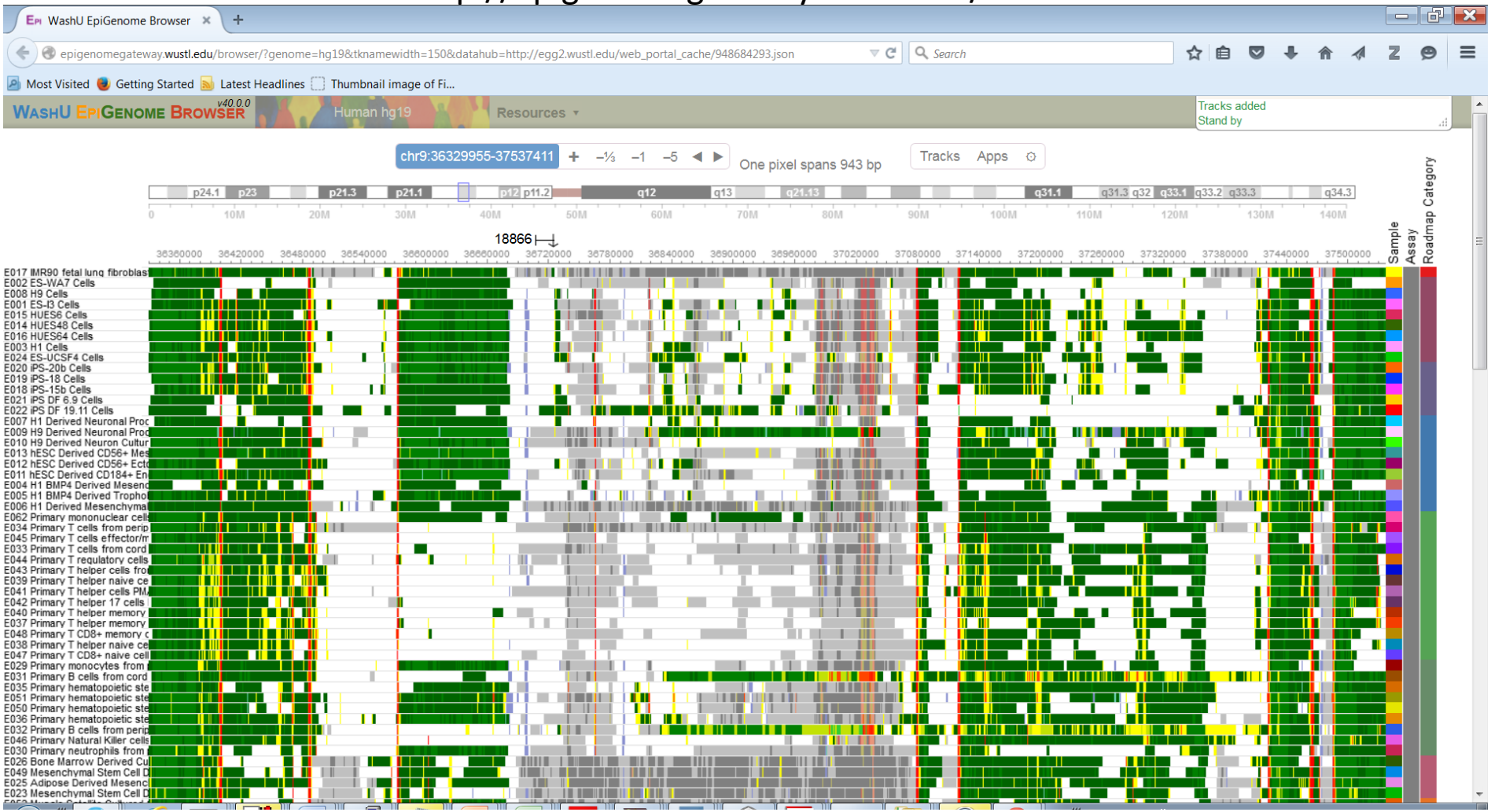


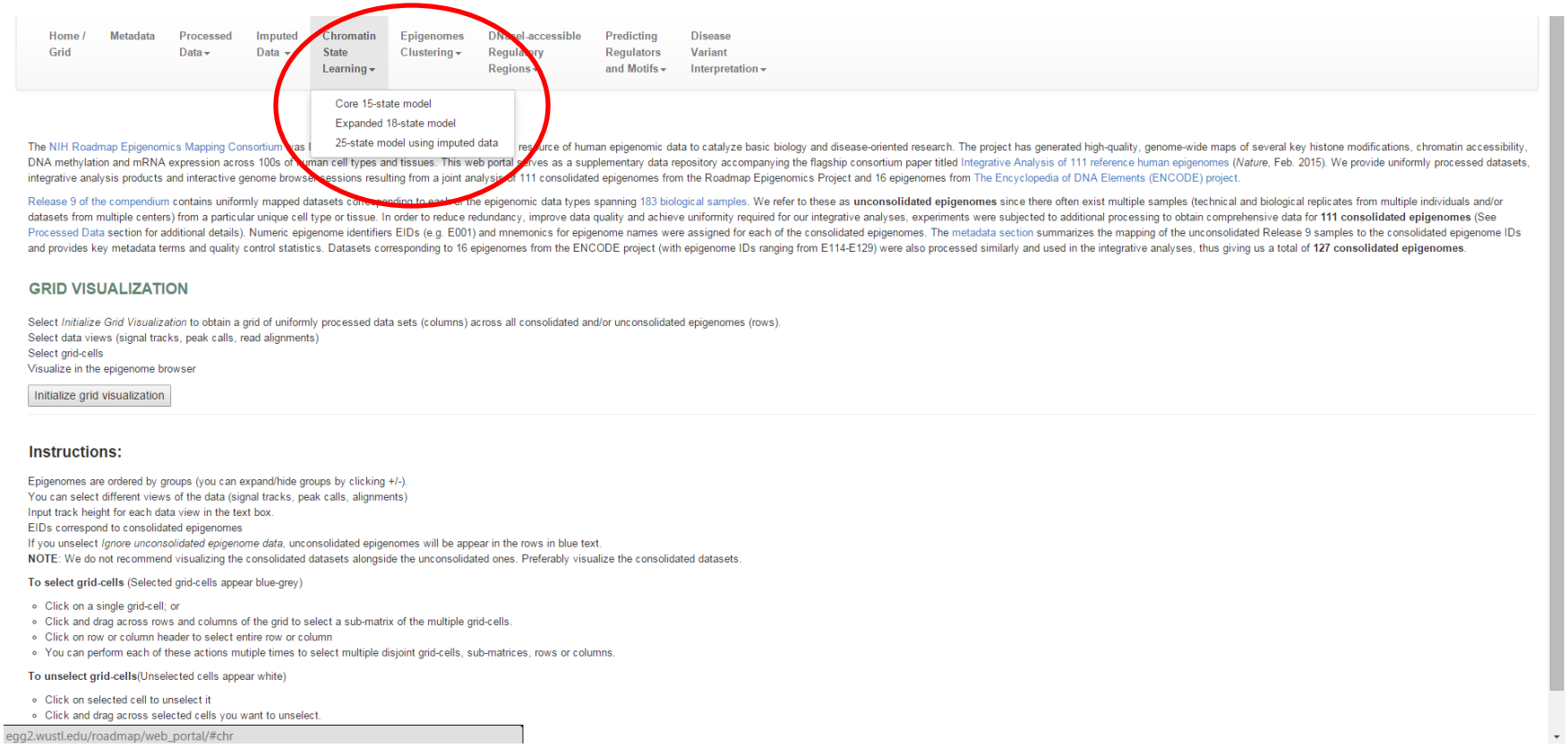
# Human Epigenome Browser at Washington University

http://epigenomegateway.wustl.edu/



# Roadmap Epigenomics Integrative Analysis Portal

http://compbio.mit.edu/roadmap



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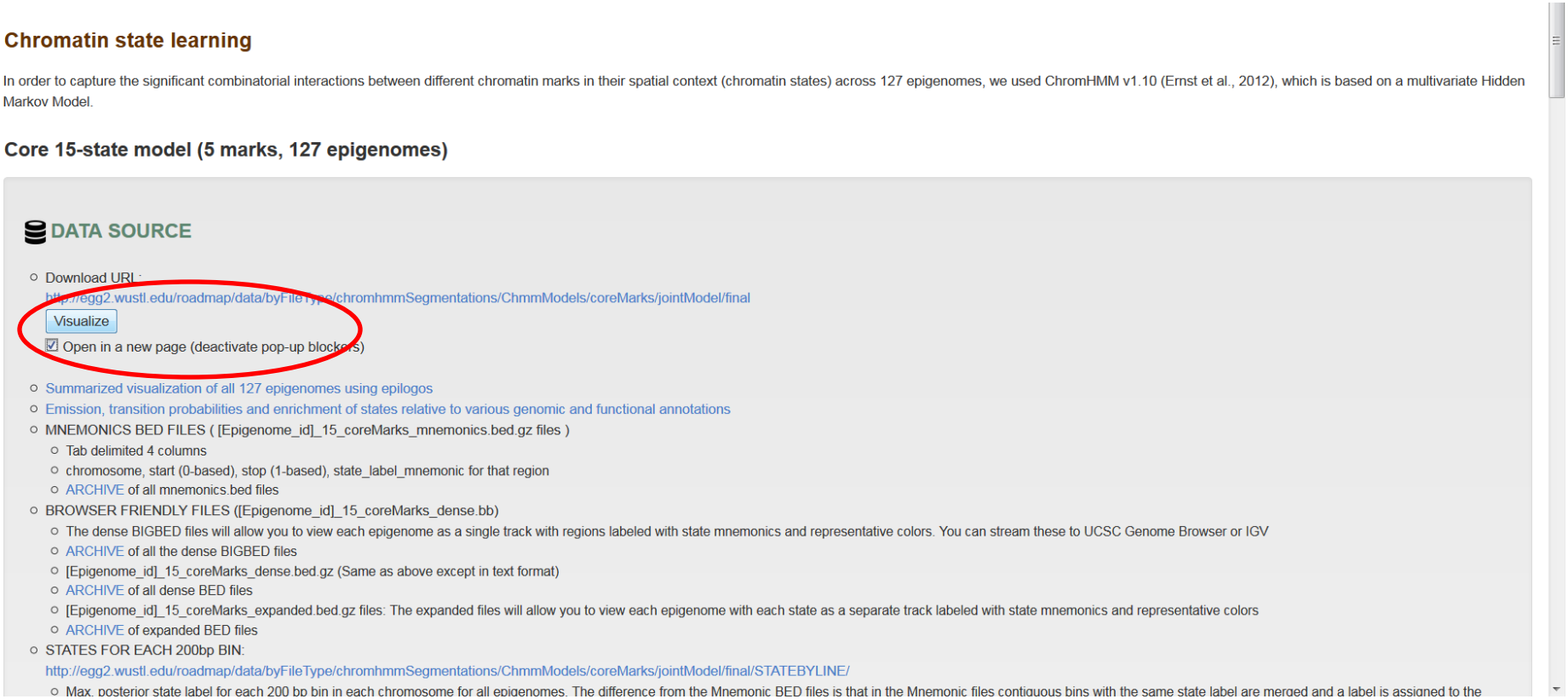


## Chromatin state learning

In order to capture the significant combinatorial interactions between different chromatin marks in their spatial context (chromatin states) across 127 epigenomes, we used ChromHMM v1.10 (Ernst et al., 2012), which is based on a multivariate Hidden Markov Model.

### Core 15-state model (5 marks, 127 epigenomes)

**DATA SOURCE**

- Download URL:
  http://egg2.wustl.edu/roadmap/data/byFileType/chromhmmSegmentations/ChmmModels/coreMarks/jointModel/final
  - Visualize
  - ☑ Open in a new page (deactivate pop-up blockers)
- Summarized visualization of all 127 epigenomes using epilogos
- Emission, transition probabilities and enrichment of states relative to various genomic and functional annotations
- MNEMONICS BED FILES ( [Epigenome_id]_15_coreMarks_mnemonics.bed.gz files )
  - Tab delimited 4 columns
  - chromosome, start (0-based), stop (1-based), state_label_mnemonic for that region
  - ARCHIVE of all mnemonics.bed files
- BROWSER FRIENDLY FILES ([Epigenome_id]_15_coreMarks_dense.bb)
  - The dense BIGBED files will allow you to view each epigenome as a single track with regions labeled with state mnemonics and representative colors. You can stream these to UCSC Genome Browser or IGV
  - ARCHIVE of all the dense BIGBED files
  - [Epigenome_id]_15_coreMarks_dense.bed.gz (Same as above except in text format)
  - ARCHIVE of all dense BED files
  - [Epigenome_id]_15_coreMarks_expanded.bed.gz files: The expanded files will allow you to view each epigenome with each state as a separate track labeled with state mnemonics and representative colors
  - ARCHIVE of expanded BED files
- STATES FOR EACH 200bp BIN:
  http://egg2.wustl.edu/roadmap/data/byFileType/chromhmmSegmentations/ChmmModels/coreMarks/jointModel/final/STATEBYLINE/
  - Max. posterior state label for each 200 bp bin in each chromosome for all epigenomes. The difference from the Mnemonic BED files is that in the Mnemonic files contiguous bins with the same state label are merged and a label is assigned to the

# Talk Outline

- Chromatin states analysis and ChromHMM
- Accessing chromatin state annotations for ENCODE2 and Roadmap Epigenomics
- Running the ChromHMM software

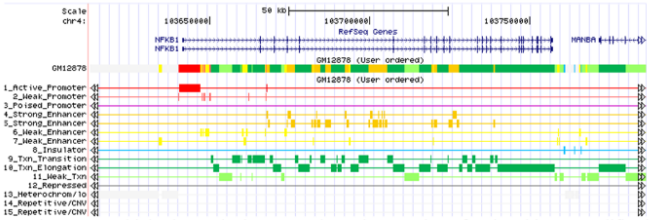
# ChromHMM Website

http://compbio.mit.edu/ChromHMM

ChromHMM: Chrom ×

compbio.mit.edu/ChromHMM/

## ChromHMM: Chromatin state discovery and characterization




ChromHMM is software for learning and characterizing chromatin states. ChromHMM can integrate multiple chromatin datasets such as ChIP-seq data of various histone modifications to discover de novo the major re-occuring combinatorial and spatial patterns of marks. ChromHMM is based on a multivariate Hidden Markov Model that explicitly models the presence or absence of each chromatin mark. The resulting model can then be used to systematically annotate a genome in one or more cell types. By automatically computing state enrichments for large-scale functional and annotation datasets ChromHMM facilitates the biological characterization of each state. ChromHMM also produces files with genome-wide maps of chromatin state annotations that can be directly visualized in a genome browser.

- ChromHMM software v1.12 (version log)
- ChromHMM manual

Software download

Quick instructions on running ChromHMM:
1. Install Java 1.5 or later if not already installed.
2. Unzip the file ChromHMM.zip
3. To try out ChromHMM learning a 10-state model on the sample data enter from a command line in the directory with the ChromHMM.jar file the command:

java -mx1600M -jar ChromHMM.jar LearnModel SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18

After termination in ~5-10 minutes a file in OUTPUTSAMPLE/webpage_10.html will be created showing output images and linking to all the output files created. If a web browser is found on the computer the webpage will automatically be opened in it.
In general binarized input for the *LearnModel* command can be generated by first running the *BinarizeBed* command on bed files with coordinates of aligned reads or the *BinarizeBam* command on bam files with the coordinates of aligned reads.

- New features in recent ChromHMM versions:

New in version 1.11: ChromHMM has a BinarizeBam command which allows binarizing bam files of aligned reads.
New in version 1.10: ChromHMM has the option for parallel training with multiprocessors leading to significantly reduced training times. Add the '-p 0' option to the LearnModel command to have ChromHMM to try to use as many processors as available or specify the maximum it should use.

- The ChromHMM software is described in:

Ernst J, Kellis M. ChromHMM: automating chromatin-state discovery and characterization. *Nature Methods*, 9:215-216, 2012.

- Here are links to some existing ChromHMM annotations in hg19 available for 127 Reference Epigenomes (Roadmap Epigenomics), 9-ENCODE cell types (from Ernst et al. Nature 2011), and 6-ENCODE cell types (from ENCODE Integrative Analysis).
- ChromHMM annotations for mm9 produced by Ross Hardison's lab as part of Mouse ENCODE is available here.
- Contact Jason Ernst (jason.ernst at ucla dot edu) with any questions, comments, or bug reports.
- Subscribe to a mailing list for announcements of new versions
- ChromHMM is released under a GPL 3 license.
- ChromHMM source code is available on GitHub here.
- Funding for ChromHMM provided by NSF Postdoctoral Fellowship 0905968 to JE and grants from the National Institutes of Health (NIH 1-RC1-HG005334 and NIH 1 U54 HG004570).

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ChromHMM: Chrom ×

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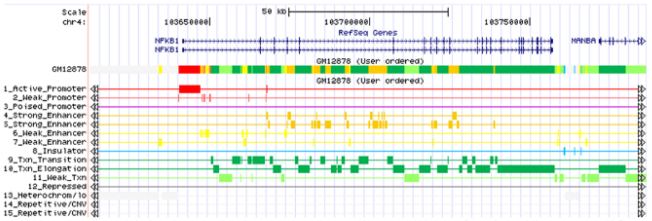


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- Contact Jason Ernst (jason.ernst at ucla dot edu) with any questions, comments, or bug reports.
- Subscribe to a mailing list for announcements of new versions
- ChromHMM is released under a GPL 3 license.
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- Funding for ChromHMM provided by NSF Postdoctoral Fellowship 0905968 to JE and grants from the National Institutes of Health (NIH 1-RC1-HG005334 and NIH 1 U54 HG004570).

# Try to Run ChromHMM on Sample Data on Your Computer

(Java should already be installed on your computer)

1. Download

http://compbio.mit.edu/ChromHMM/ChromHMM.zip

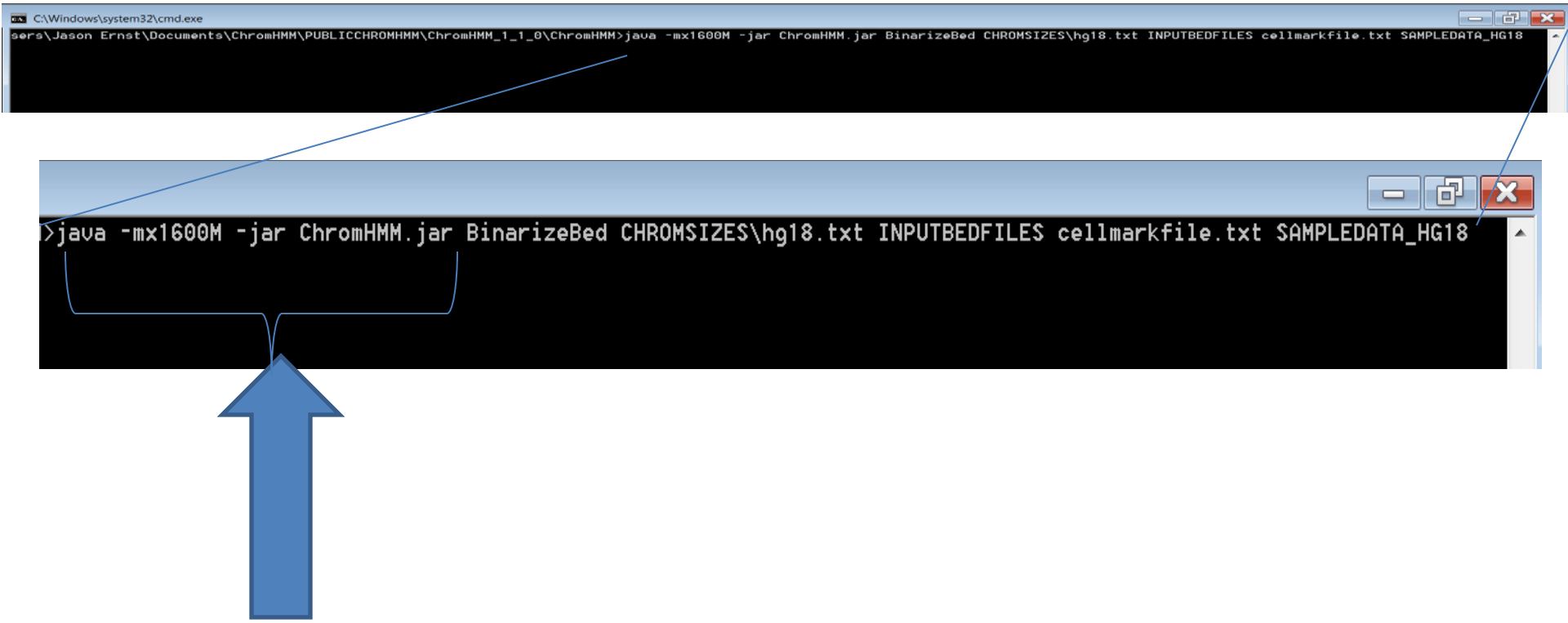
2. Unzip ChromHMM.zip
3. Open a command line
4. Change into the ChromHMM directory
5. Enter the command:

```
java -mx1600M -jar ChromHMM.jar LearnModel -p 0
SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
```

# Input to ChromHMM

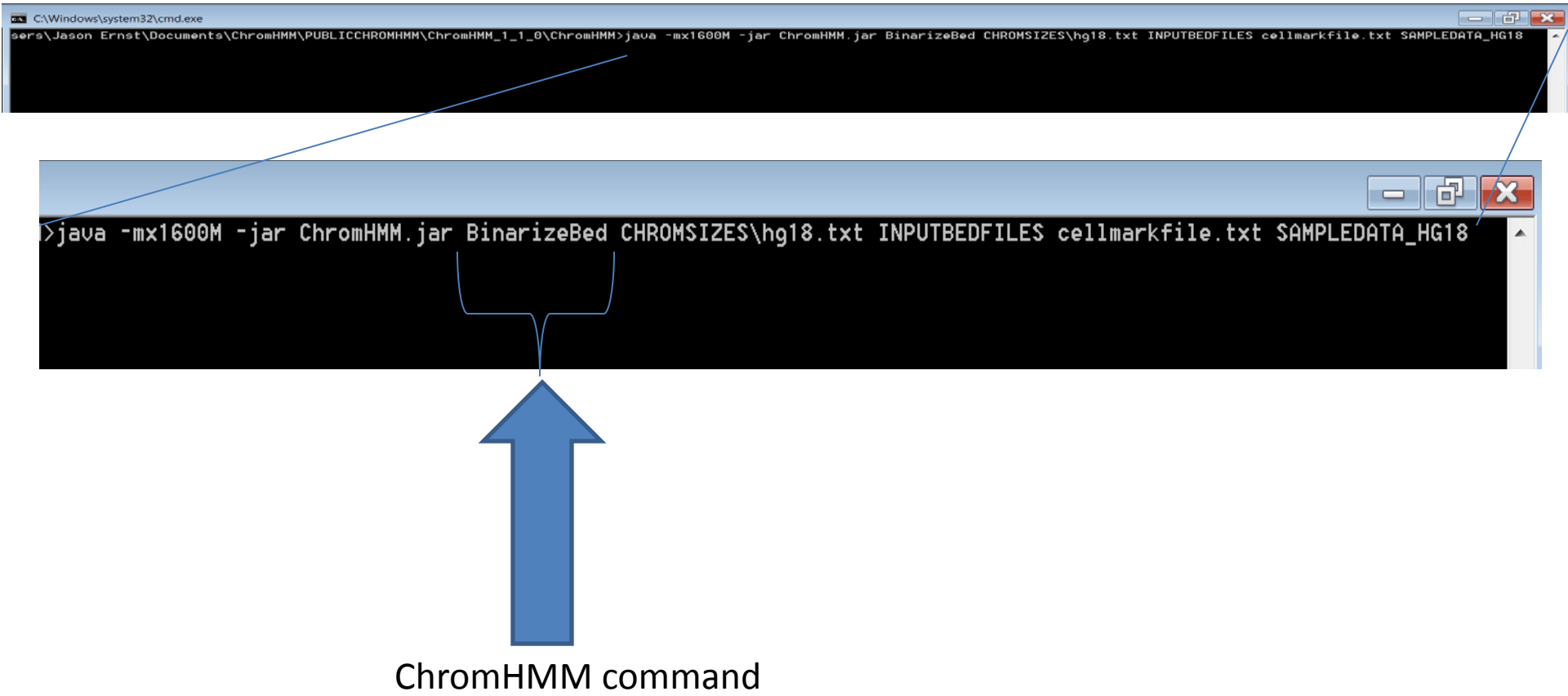
- ChromHMM models are learned from binarized data using its `LearnModel` command
- Binarized data is typically obtained starting from aligned reads.
  - Apply `BinarizeBed` if reads are in BED format
  - Apply `BinarizeBam` if reads are in BAM format

# BinarizeBed



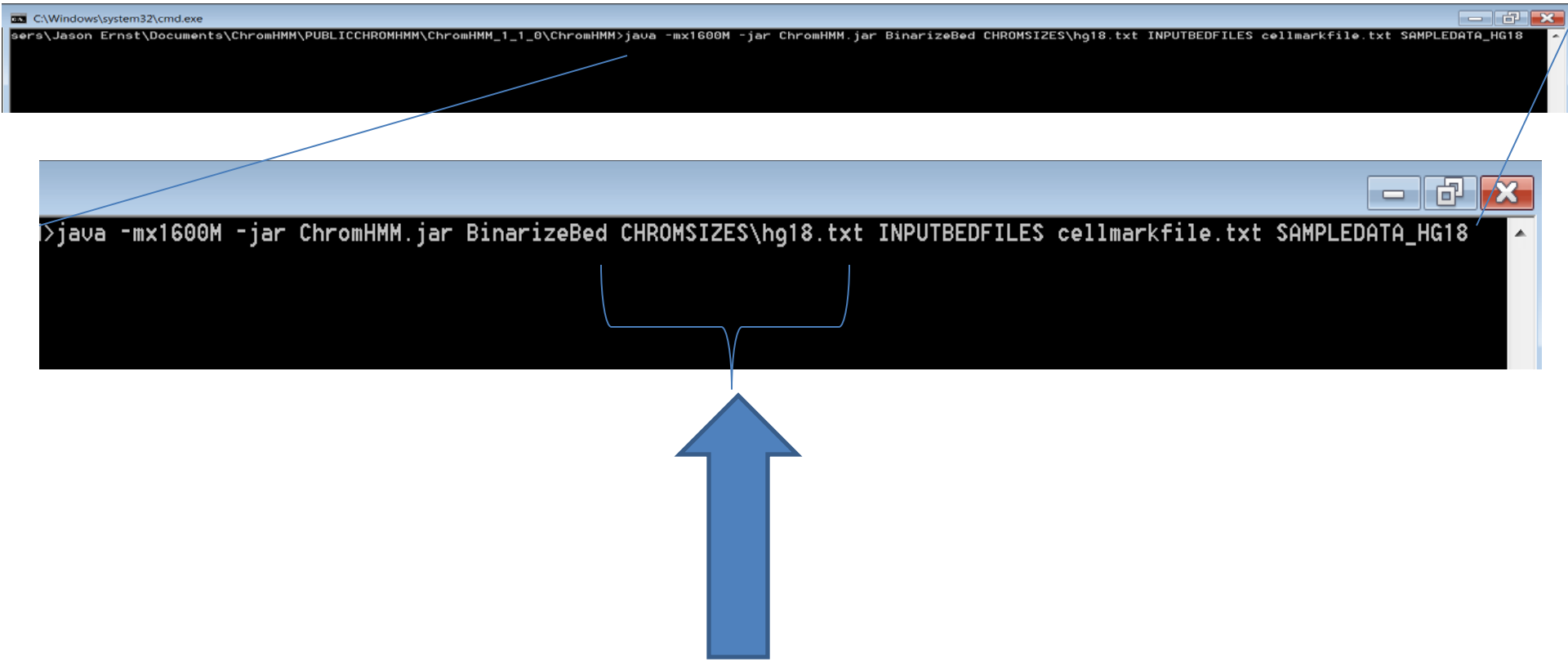

Java command '-mx1600M' specifies memory to Java

# BinarizeBed



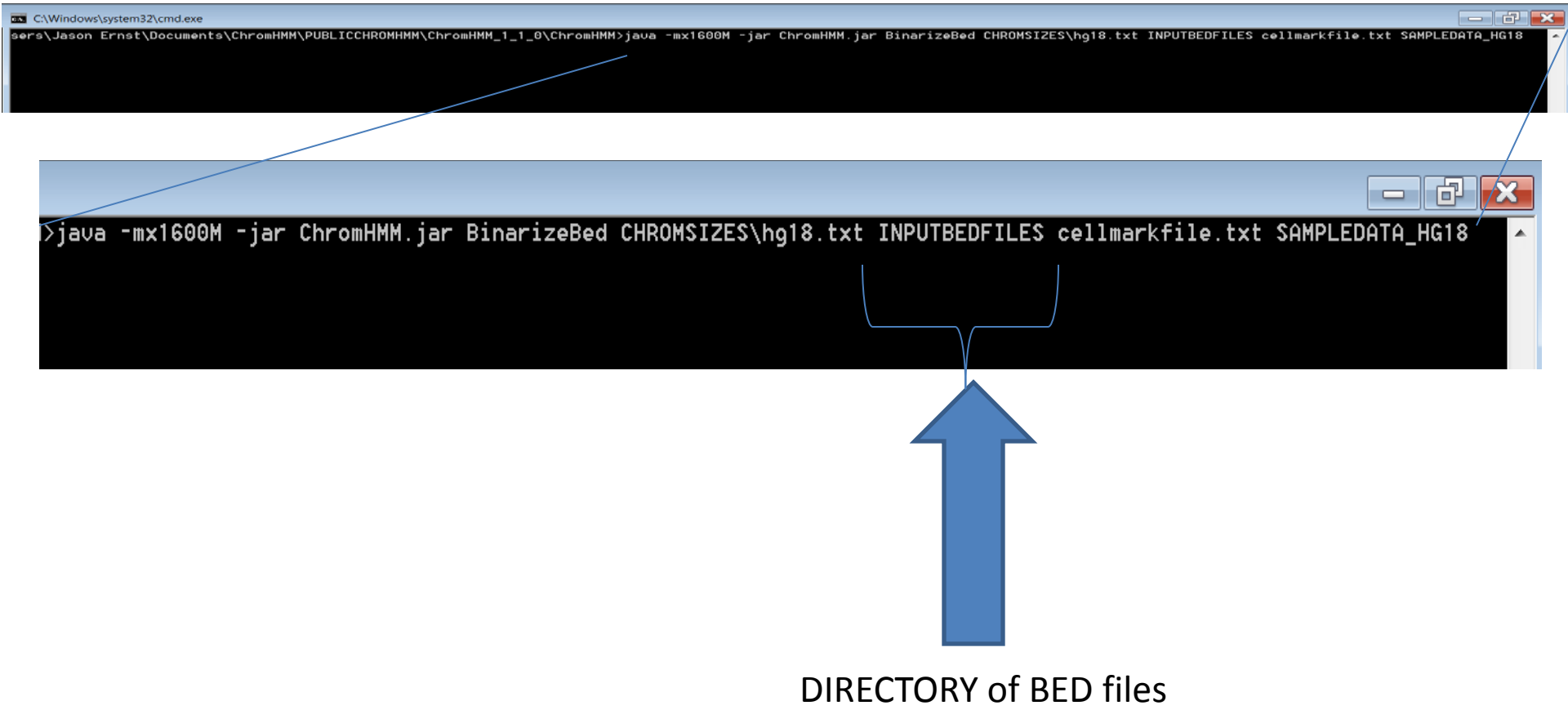

ChromHMM command

# BinarizeBed

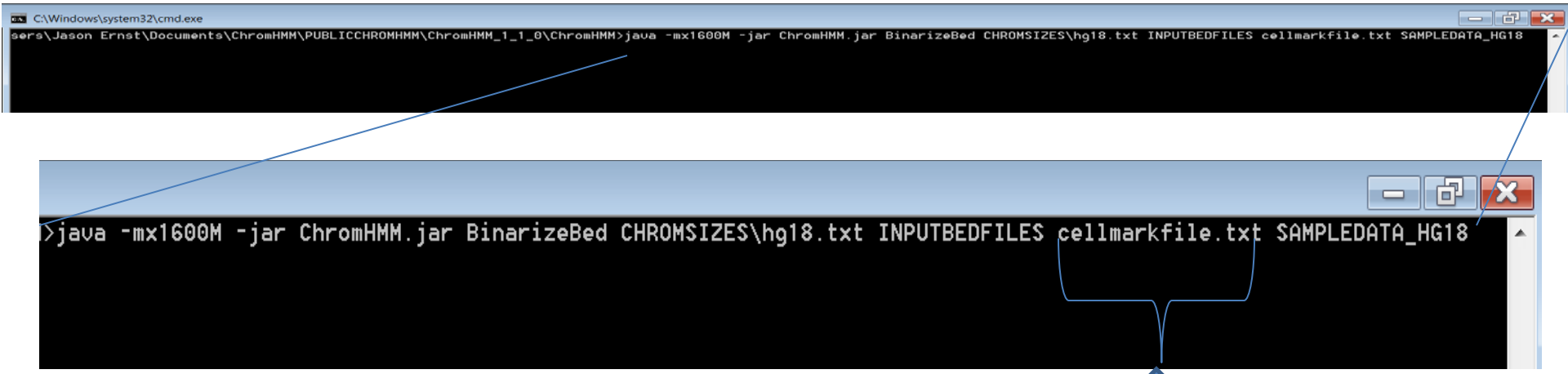



File with the chromosome lengths for the assembly

# BinarizeBed



# BinarizeBed



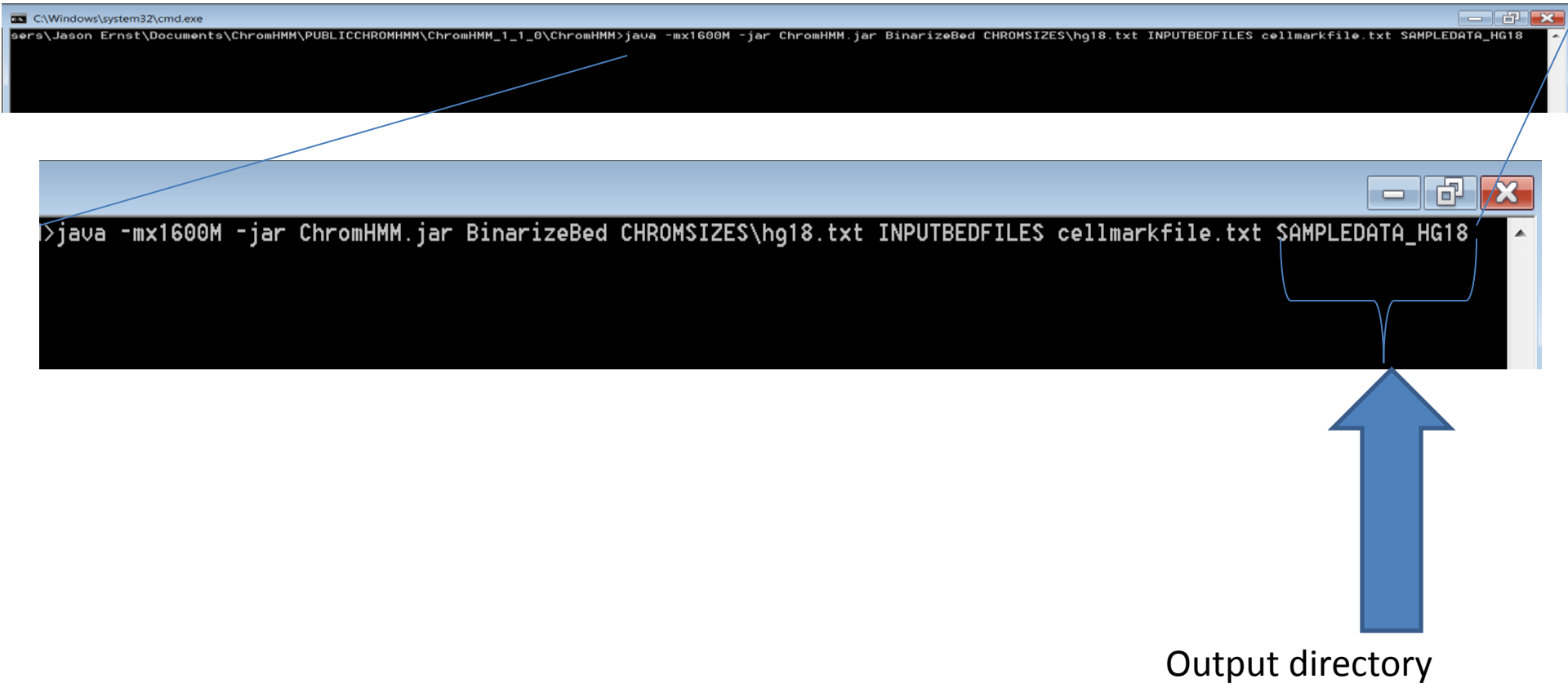

```
cell1 mark1 cell1_mark1.bed   cell1_control.bed
cell1 mark2 cell1_mark2.bed   cell1_control.bed
cell2 mark1 cell2_mark1.bed   cell2_control.bed
cell2 mark2 cell2_mark2.bed   cell2_control.bed
```

cell mark cell-mark

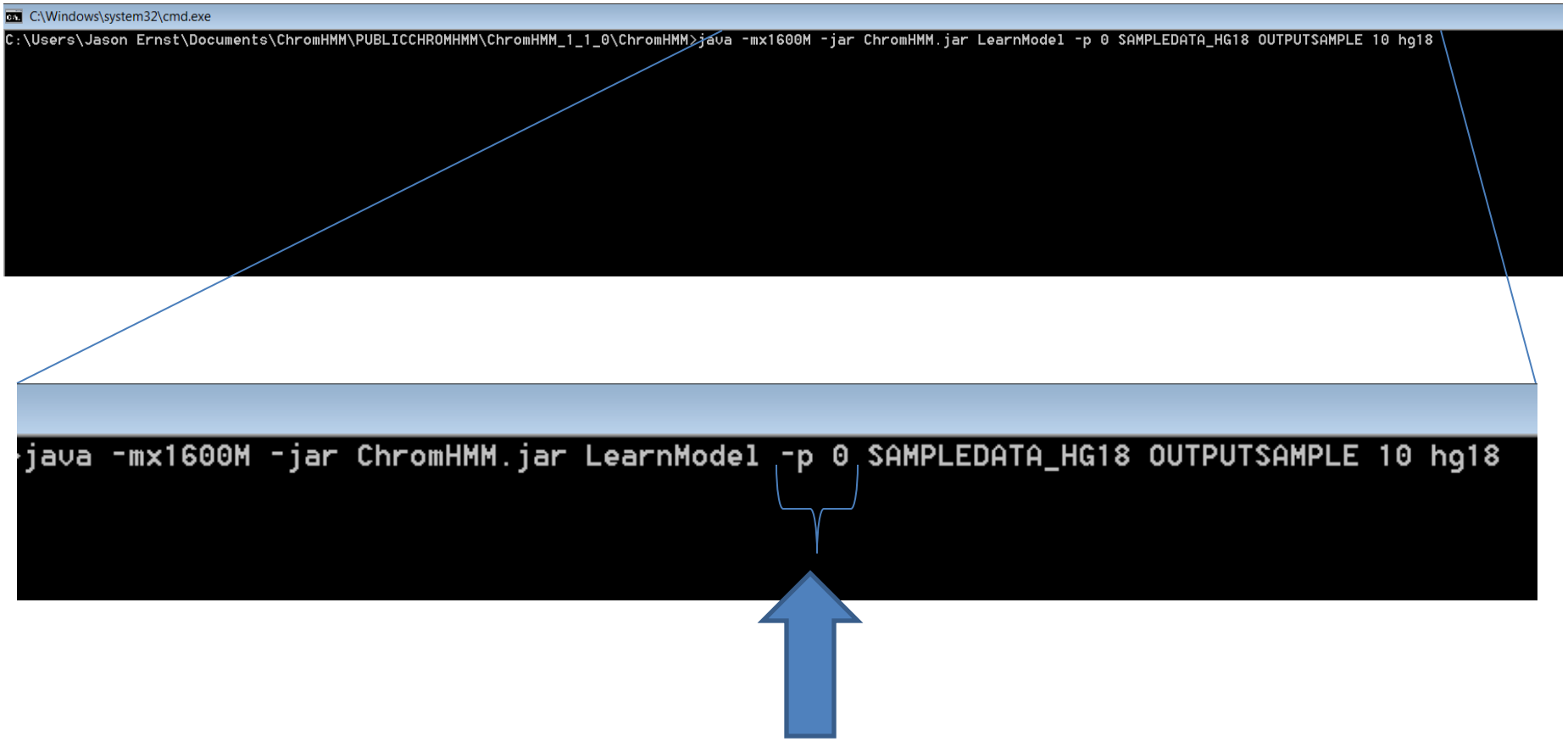
Cell-mark-file table

Control data – is optional and can also be treated as a mark

# BinarizeBed

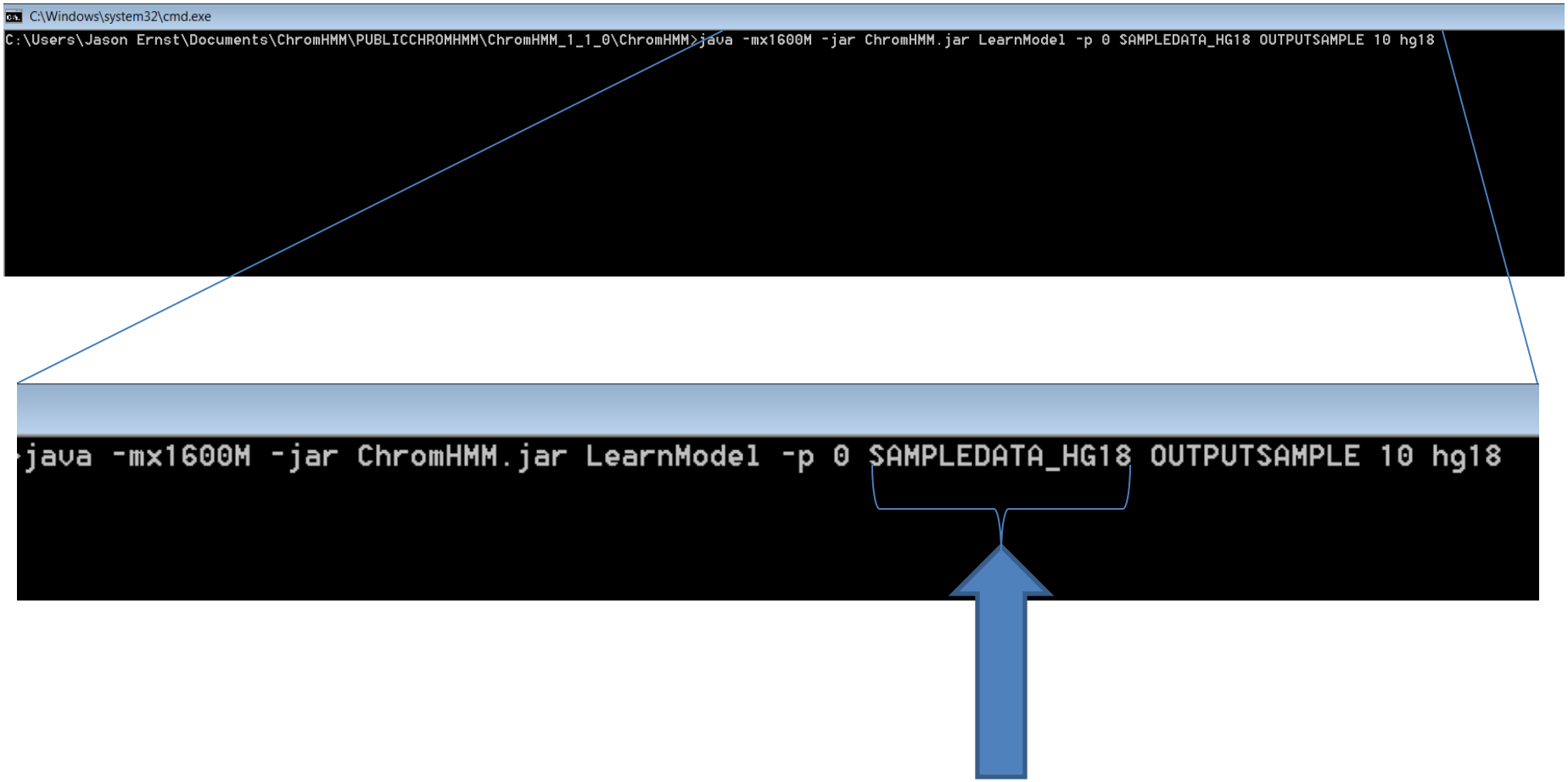


# LearnModel



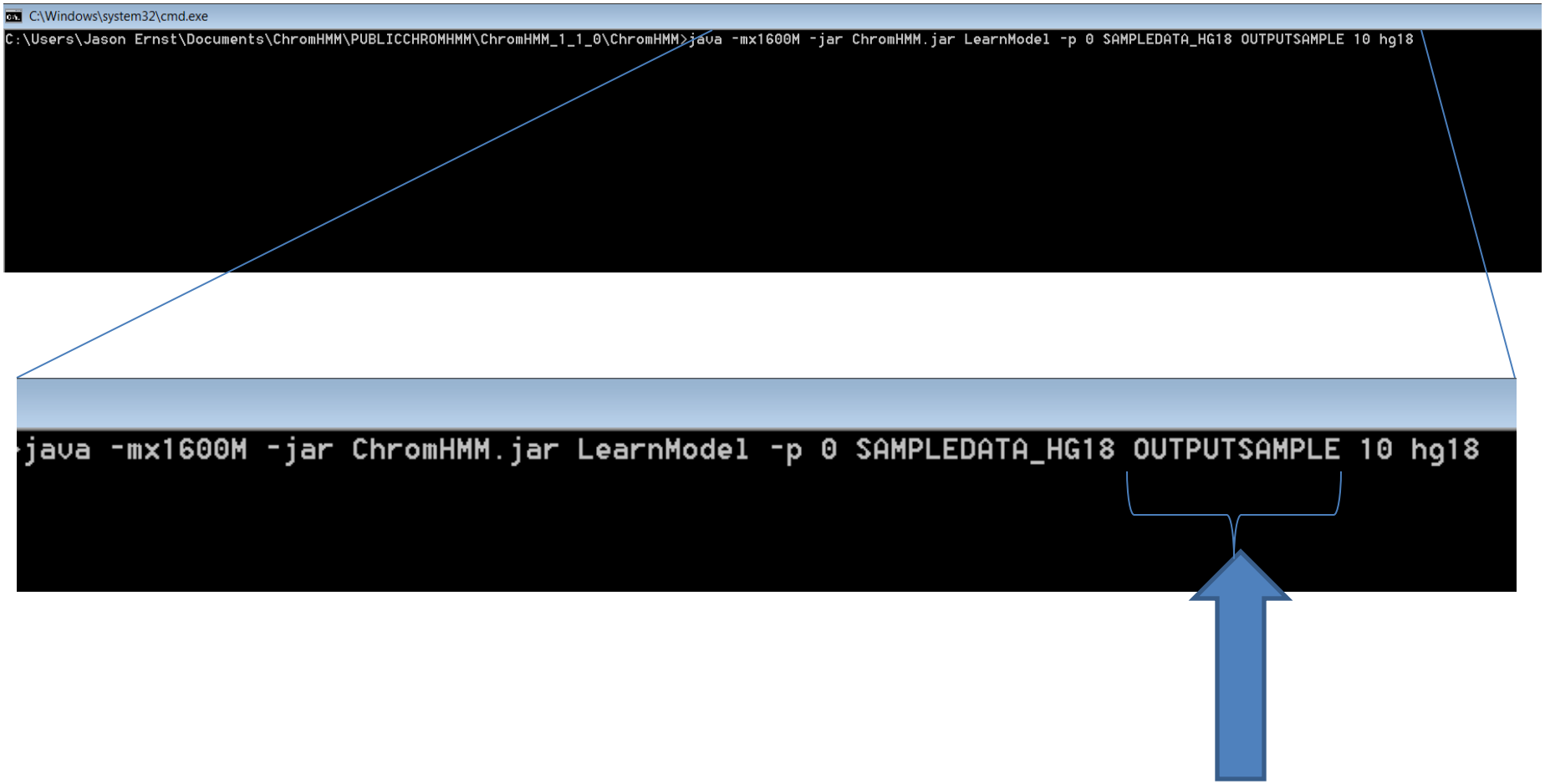

‘-p 0’ Use as many processors as available
‘-p N’ Use up to N processors (default N=1)

# LearnModel

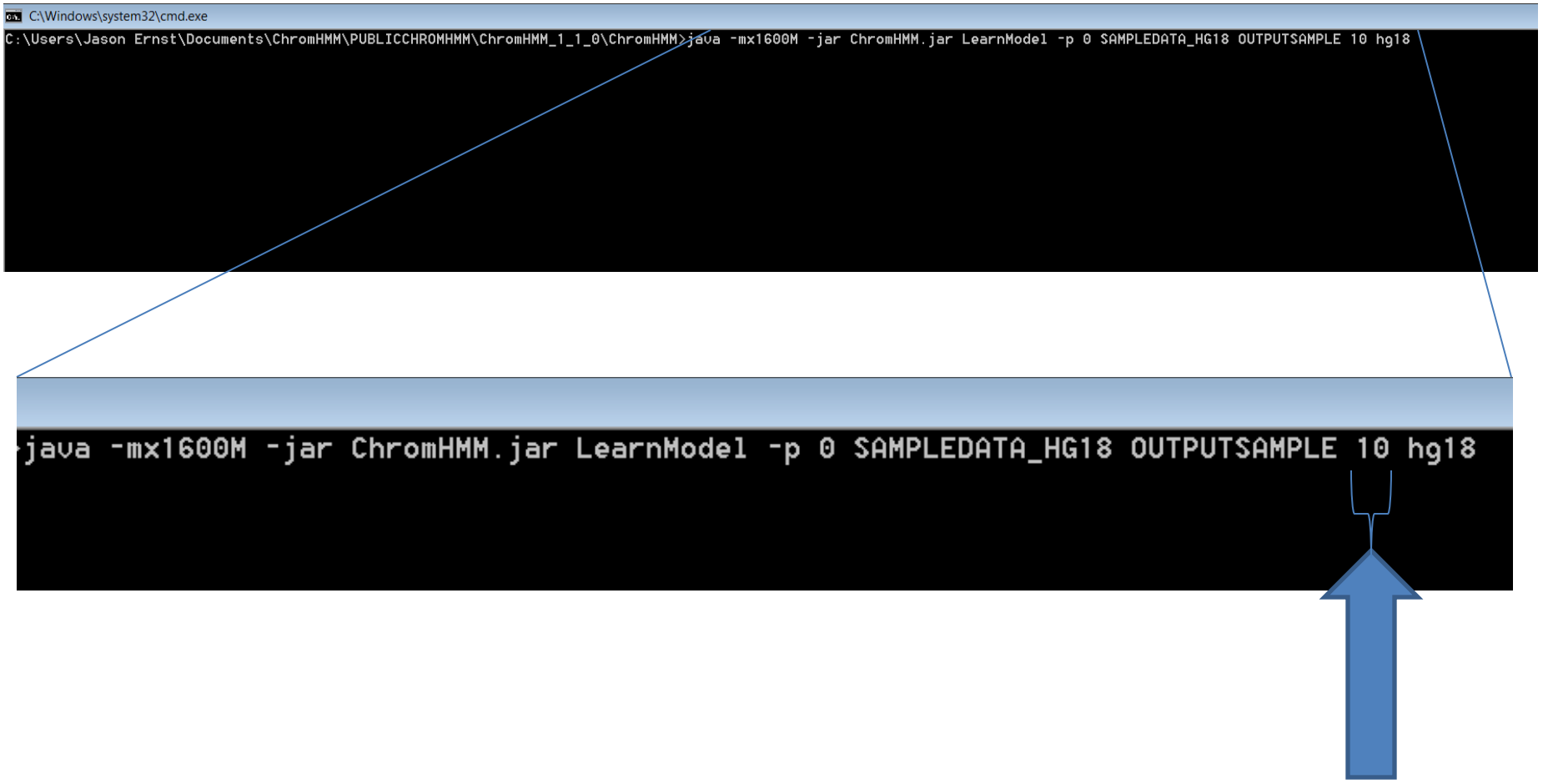



Directory with the Binarized Input

# LearnModel


C:\Windows\system32\cmd.exe
C:\Users\Jason Ernst\Documents\ChromHMM\PUBLICCHROMHMM\ChromHMM_1_1_0\ChromHMM>java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
Directory where the output goes

# LearnModel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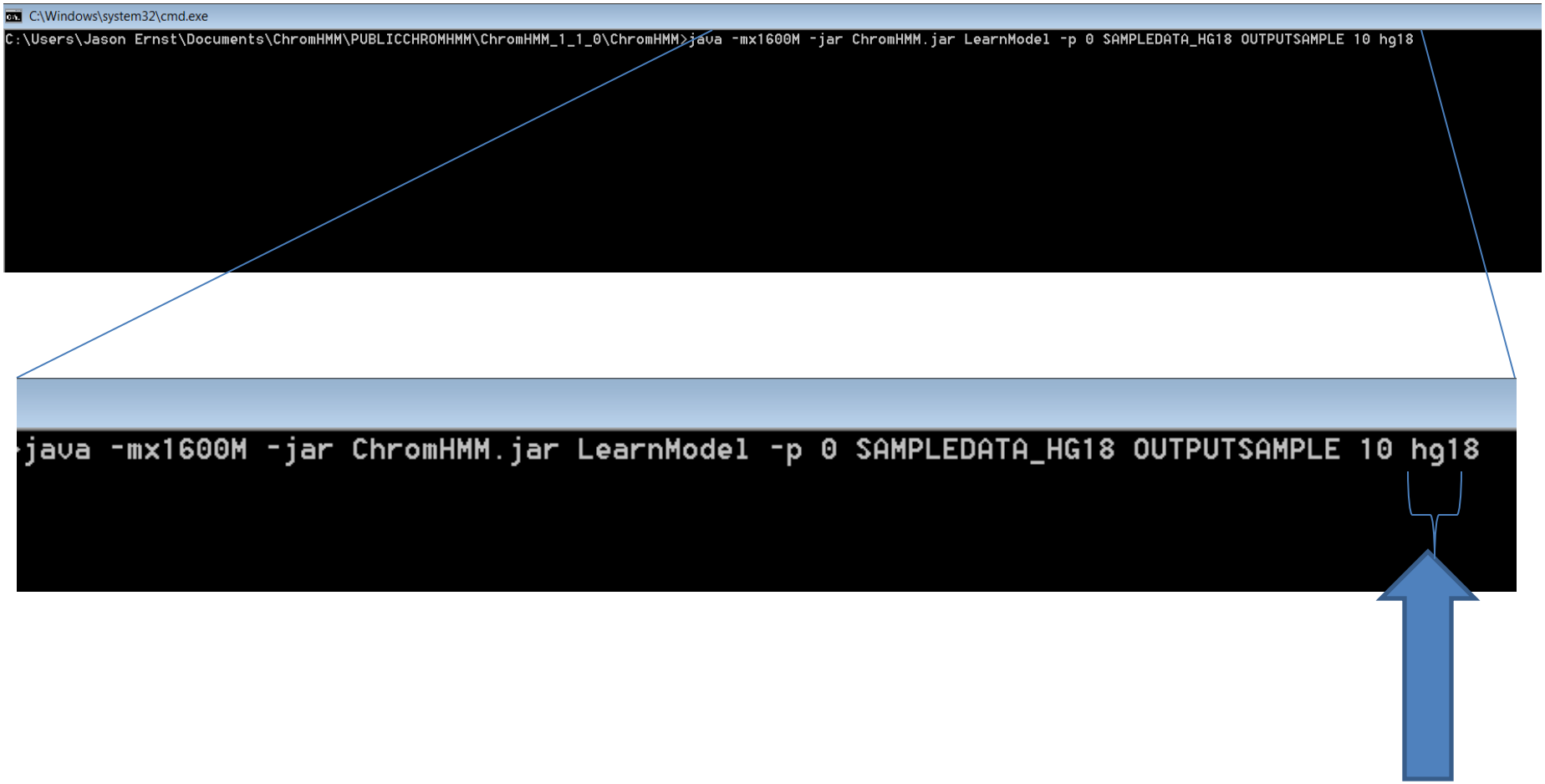
C:\Users\Jason Ernst\Documents\ChromHMM\PUBLICCHROMHMM\ChromHMM_1_1_0\ChromHMM>java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
Number of states

# LearnModel


C:\Windows\system32\cmd.exe
C:\Users\Jason Ernst\Documents\ChromHMM\PUBLICCHROMHMM\ChromHMM_1_1_0\ChromHMM>java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
java -mx1600M -jar ChromHMM.jar LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18
Genome assembly

# ChromHMM Report

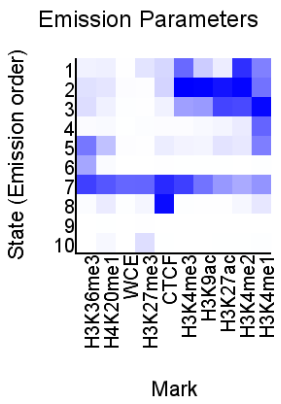
webpage_10.html

file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

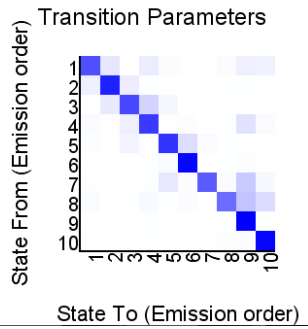
## ChromHMM Report

Input Directory: SAMPLEDATA_HG18
Output Directory: OUTPUTSAMPLE
Number of States: 10
Assembly: hg18
Full ChromHMM command: LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18

## Model Parameters




- Emission Parameter SVG File
- Emission Parameter Tab-Delimited Text File



# ChromHMM Report

webpage_10.html

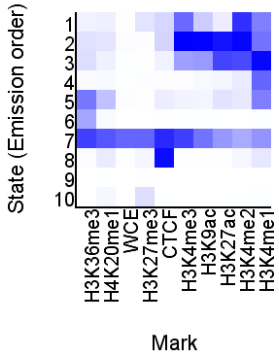
file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

## ChromHMM Report

Input Directory: SAMPLEDATA_HG18
Output Directory: OUTPUTSAMPLE
Number of States: 10
Assembly: hg18
Full ChromHMM command: LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18

## Model Parameters

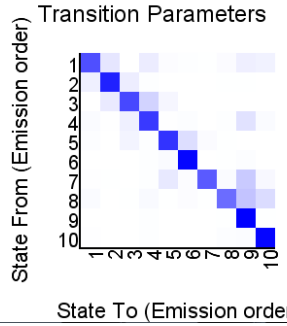
Emission Parameters




Input Directory: SAMPLEDATA_HG18
Output Directory: OUTPUTSAMPLE
Number of States: 10
Assembly: hg18
Full ChromHMM command: LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18

- Emission Parameter SVG File
- Emission Parameter Tab-Delimited Text File

Transition Parameters



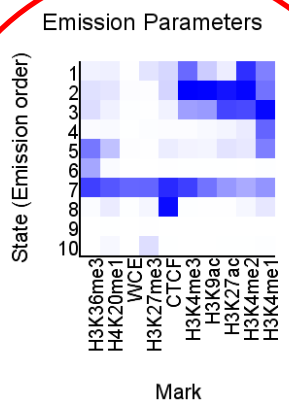
# Emission Parameters

webpage_10.html

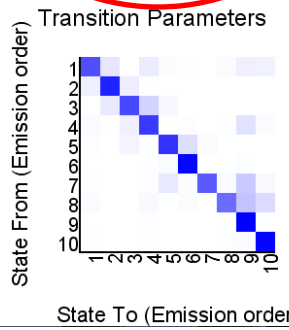
file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1 0/ChromHMM/OUTPUTSAMPLE/webpage 10.html

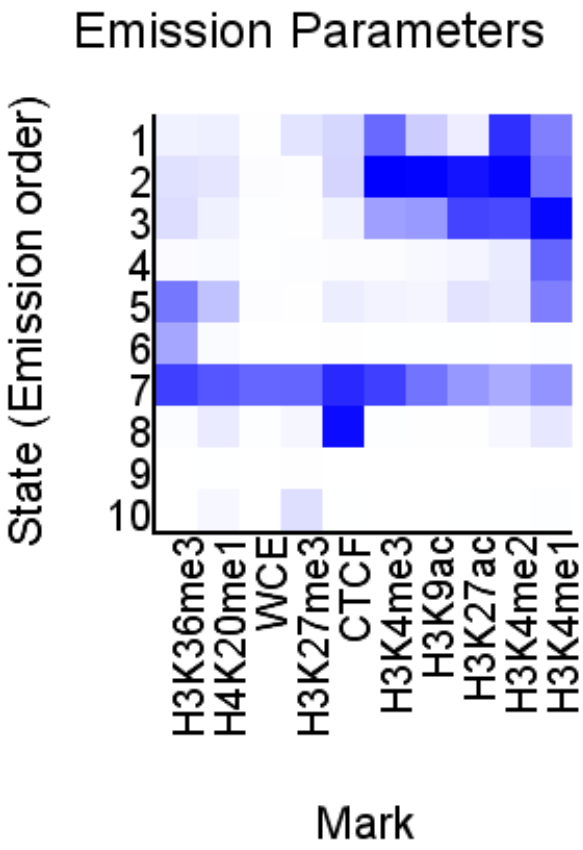
Input Directory: SAMPLEDATA_HG18
Output Directory: OUTPUTSAMPLE
Number of States: 10
Assembly: hg18
Full ChromHMM command: LearnModel -p 0 SAMPLEDATA_HG18 OUTPUTSAMPLE 10 hg18

## Model Parameters




- Emission Parameter SVG File
- Emission Parameter Tab-Delimited Text File




- Emission Parameter SVG File
- Emission Parameter Tab-Delimited Text File

# Transition Parameters

webpage_10.html

file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

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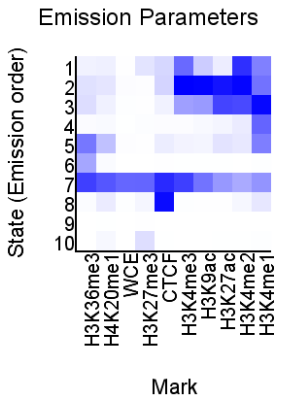
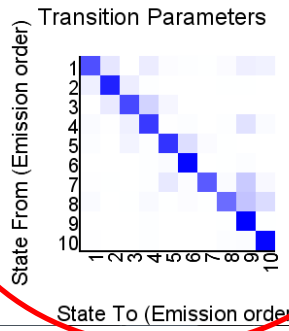
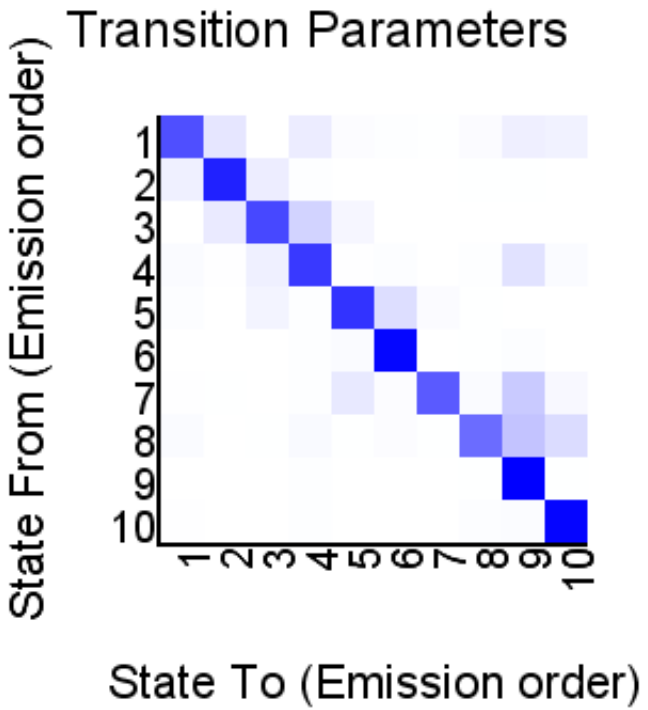



- Emission Parameter SVG File
- Emission Parameter Tab-Delimited Text File




- Transition Parameter SVG File
- Transition Parameter Tab-Delimited Text File

# Model Parameter File

webpage_10.html

file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

- Transition Parameter SVG File
- Transition Parameter Tab-Delimited Text File

- All Model Parameters Tab-Delimited Text File

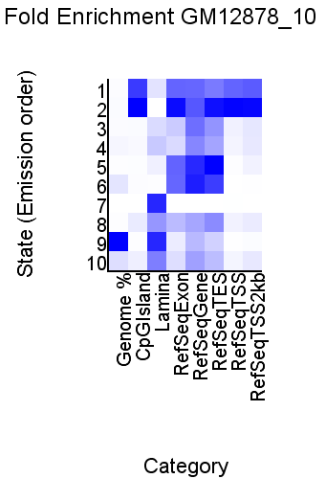
## Genome Segmentation Files

- GM12878_10 Segmentation File (Four Column Bed File)
- K562_10 Segmentation File (Four Column Bed File)

Custom Tracks for loading into the UCSC Genome Browser:
- GM12878_10 Browser Custom Track Dense File
- GM12878_10 Browser Custom Track Expanded File
- K562_10 Browser Custom Track Dense File
- K562_10 Browser Custom Track Expanded File

## State Enrichments

### GM12878_10 Enrichments




- GM12878_10 Overlap Enrichment SVG File
- GM12878_10 Overlap Enrichment Tab-Delimited Text File

# Segmentation File

webpage_10.html

file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

- Transition Parameter SVG File
- Transition Parameter Tab-Delimited Text File

- All Model Parameters Tab-Delimited Text File

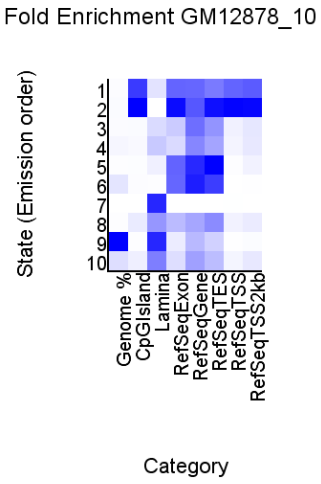
## Genome Segmentation Files

- GM12878_10 Segmentation File (Four Column Bed File)
- K562_10 Segmentation File (Four Column Bed File)

Custom Tracks for loading into the UCSC Genome Browser:
- GM12878_10 Browser Custom Track Dense File
- GM12878_10 Browser Custom Track Expanded File
- K562_10 Browser Custom Track Dense File
- K562_10 Browser Custom Track Expanded File

## State Enrichments

### GM12878_10 Enrichments




- GM12878_10 Overlap Enrichment SVG File
- GM12878_10 Overlap Enrichment Tab-Delimited Text File

GM12878_10_segments.bed - Notepad

File Edit Format View Help

| | | | |
|---|---|---|---|
| chr11 | 0 | 58000 | E9 |
| chr11 | 58000 | 58400 | E8 |
| chr11 | 58400 | 61400 | E9 |
| chr11 | 61400 | 61800 | E8 |
| chr11 | 61800 | 66800 | E9 |
| chr11 | 66800 | 67600 | E4 |
| chr11 | 67600 | 75600 | E9 |
| chr11 | 75600 | 76000 | E8 |
| chr11 | 76000 | 87600 | E9 |
| chr11 | 87600 | 88600 | E10 |
| chr11 | 88600 | 116200 | E9 |
| chr11 | 116200 | 116400 | E1 |
| chr11 | 116400 | 116600 | E10 |
| chr11 | 116600 | 117000 | E8 |
| chr11 | 117000 | 120600 | E9 |
| chr11 | 120600 | 121000 | E8 |
| chr11 | 121000 | 165400 | E9 |
| chr11 | 165400 | 166000 | E7 |
| chr11 | 166000 | 170000 | E10 |
| chr11 | 170000 | 171000 | E8 |
| chr11 | 171000 | 173200 | E9 |
| chr11 | 173200 | 173600 | E7 |
| chr11 | 173600 | 174000 | E9 |
| chr11 | 174000 | 174400 | E8 |
| chr11 | 174400 | 177000 | E9 |
| chr11 | 177000 | 177600 | E4 |
| chr11 | 177600 | 178800 | E3 |
| chr11 | 178800 | 179800 | E5 |
| chr11 | 179800 | 180600 | E3 |
| chr11 | 180600 | 181000 | E2 |
| chr11 | 181000 | 181600 | E1 |
| chr11 | 181600 | 182200 | E2 |
| chr11 | 182200 | 182800 | E1 |
| chr11 | 182800 | 183000 | E4 |
| chr11 | 183000 | 184600 | E10 |
| chr11 | 184600 | 184800 | E7 |
| chr11 | 184800 | 186600 | E10 |
| chr11 | 186600 | 189800 | E9 |
| chr11 | 189800 | 193000 | E6 |
| chr11 | 193000 | 195600 | E5 |
| chr11 | 195600 | 195800 | E3 |
| chr11 | 195800 | 200400 | E2 |
| chr11 | 200400 | 201200 | E3 |
| chr11 | 201200 | 201800 | E5 |
| chr11 | 201800 | 205800 | E6 |
| chr11 | 205800 | 210600 | E9 |
| chr11 | 210600 | 215400 | E6 |
| chr11 | 215400 | 215600 | E4 |
| chr11 | 215600 | 216400 | E2 |
| chr11 | 216400 | 224200 | E9 |
| chr11 | 224200 | 224400 | E4 |
| chr11 | 224400 | 225200 | E9 |
| chr11 | 225200 | 225600 | E1 |
| chr11 | 225600 | 228200 | E2 |
| chr11 | 228200 | 228800 | E1 |

# Browser Files

webpage_10.html

file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

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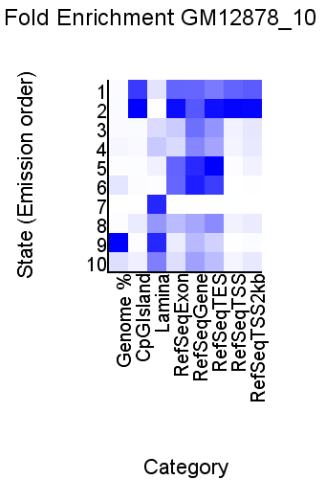
- K562_10 Browser Custom Track Expanded File

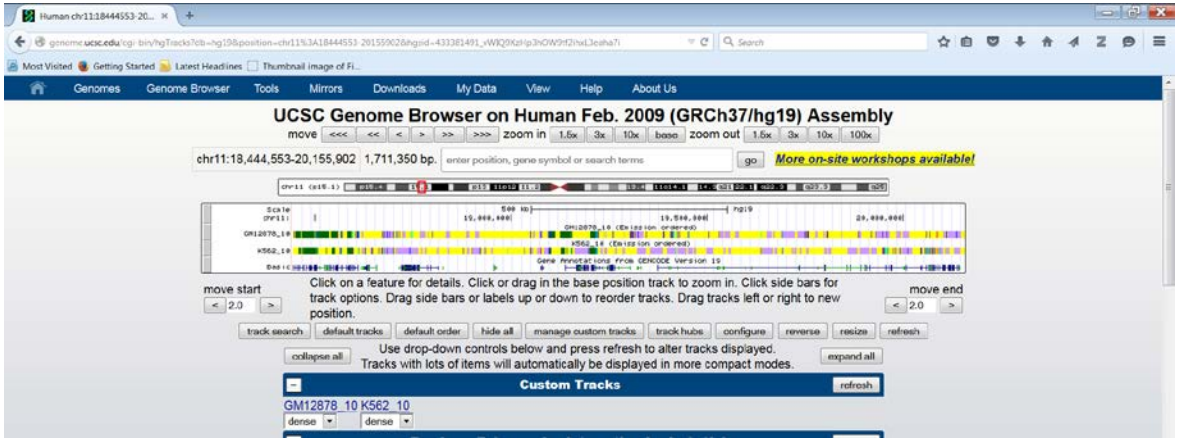
## State Enrichments

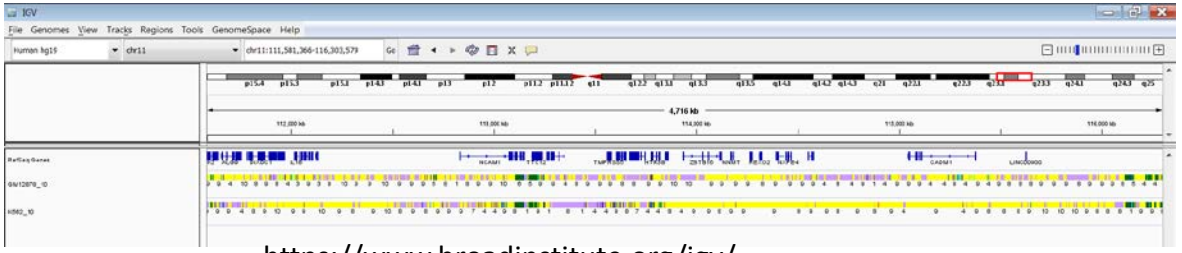
### GM12878_10 Enrichments




- GM12878_10 Overlap Enrichment SVG File
- GM12878_10 Overlap Enrichment Tab-Delimited Text File

Can load into browser UCSC Genome, IGV




https://www.broadinstitute.org/igv/

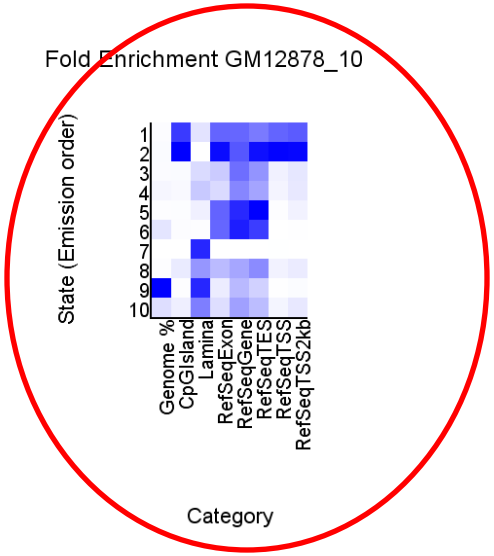
# Enrichments

webpage_10.html

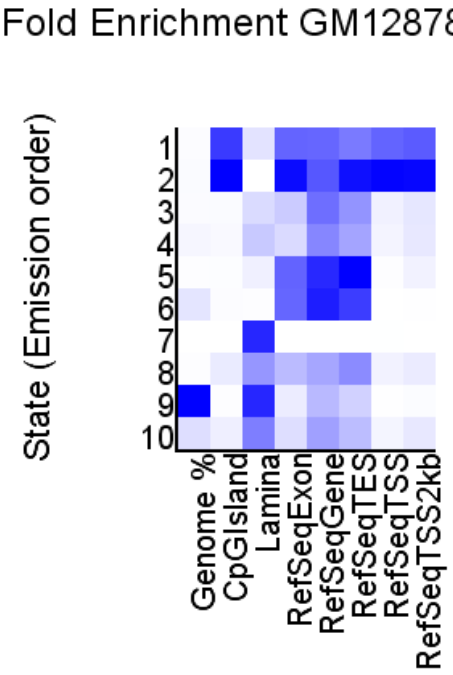
file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

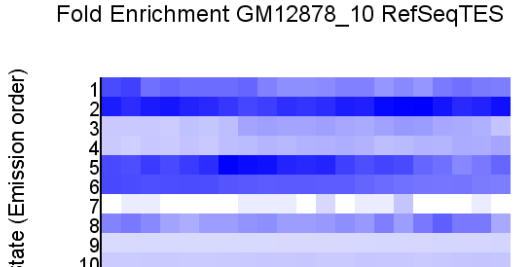
## State Enrichments

### GM12878_10 Enrichments




- GM12878_10 Overlap Enrichment SVG File
- GM12878_10 Overlap Enrichment Tab-Delimited Text File




Category

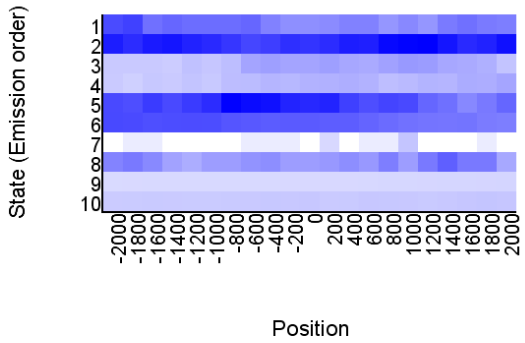
- GM12878_10 Overlap Enrichment SVG File
- GM12878_10 Overlap Enrichment Tab-Delimited Text File

# Positional Plots

webpage_10.html

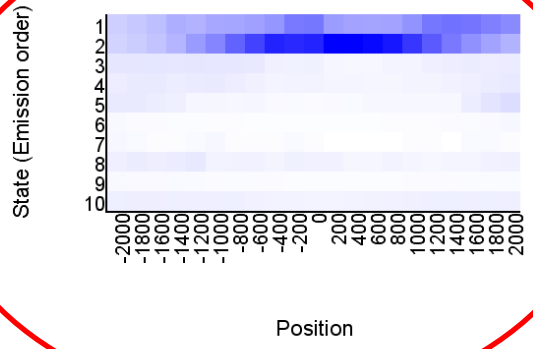
file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

Fold Enrichment GM12878_10 RefSeqTES



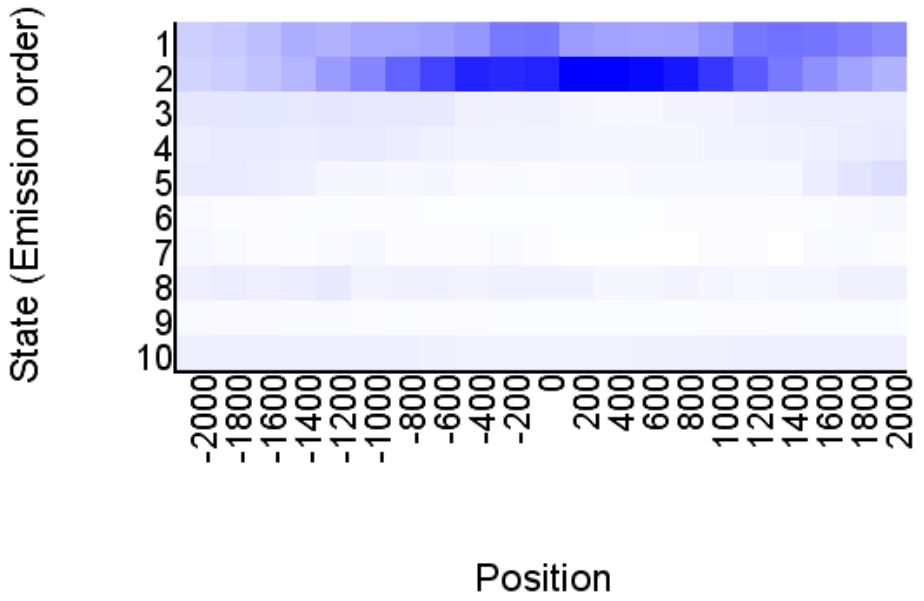

- GM12878_10_RefSeqTES_neighborhood Enrichment SVG File
- GM12878_10_RefSeqTES_neighborhood Enrichment Tab-Delimited Text File

Fold Enrichment GM12878_10 RefSeqTSS




- GM12878_10_RefSeqTSS_neighborhood Enrichment SVG File
- GM12878_10_RefSeqTSS_neighborhood Enrichment Tab-Delimited Text File

Fold Enrichment GM12878_10 RefSeqTSS





- GM12878_10_RefSeqTSS_neighborhood Enrichment SVG File
- GM12878_10_RefSeqTSS_neighborhood Enrichment Tab-Delimited Text File

# Enrichments for Additional Cell Types

webpage_10.html

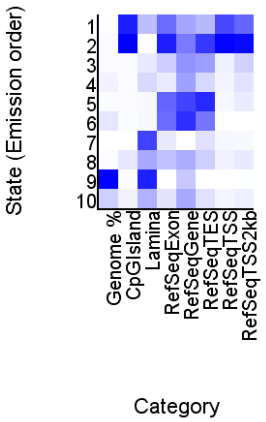
file:///C:/Users/Jason%20Ernst/Documents/ChromHMM/PUBLICCHROMHMM/ChromHMM_1_1_0/ChromHMM/OUTPUTSAMPLE/webpage_10.html

Position

- GM12878_10_RefSeqTSS_neighborhood Enrichment SVG File
- GM12878_10_RefSeqTSS_neighborhood Enrichment Tab-Delimited Text File

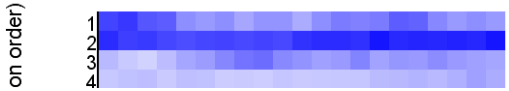
**K562_10 Enrichments**

Fold Enrichment K562_10



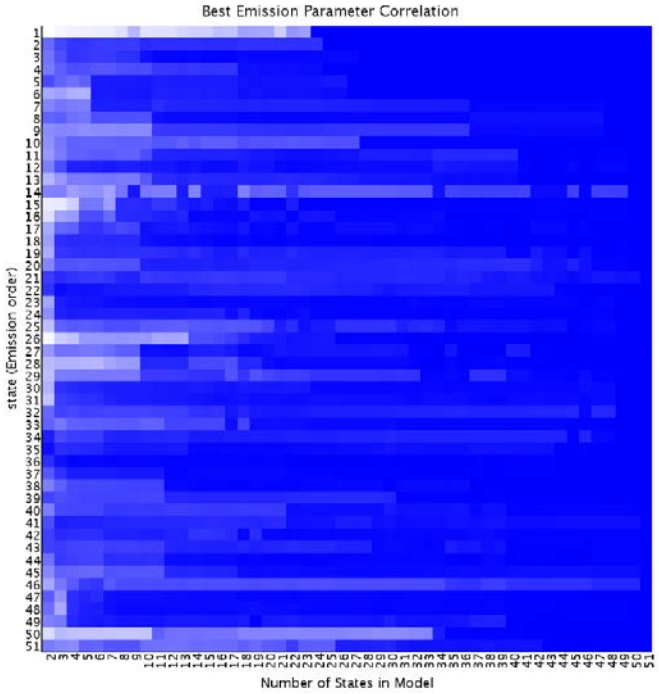

- K562_10 Overlap Enrichment SVG File
- K562_10 Overlap Enrichment Tab-Delimited Text File

Fold Enrichment K562_10 RefSeqTES



# Additional Commands

- CompareModels – the command allows the comparison of the emission parameters of a selected model to a set of models in terms of correlation.

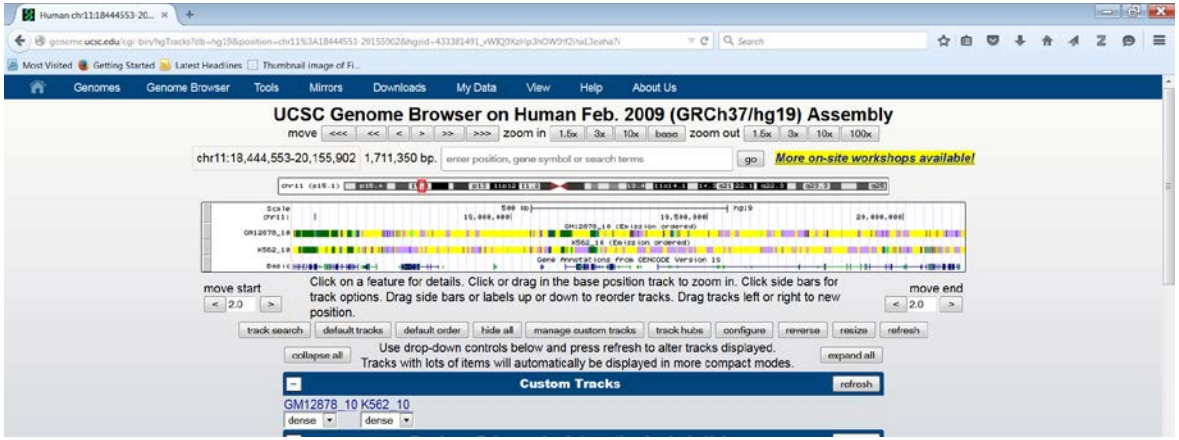



```
CompareModels [-color r,g,b] referencemodel comparedir outputprefix
```

# Additional Commands

- MakeBrowserFiles – (re)generates browser files from segmentation files and allows specifying the coloring

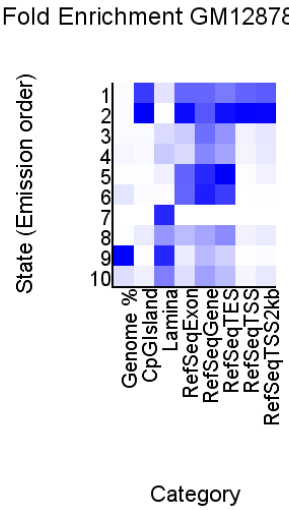
```
MakeBrowserFiles [-c colormappingfile][-m labelmappingfile][-n numstates]
segmentfile segmentationname outputfileprefix
```



# Additional Commands

- OverlapEnrichment – (re)computes enrichments of a segmentation for a set of annotations

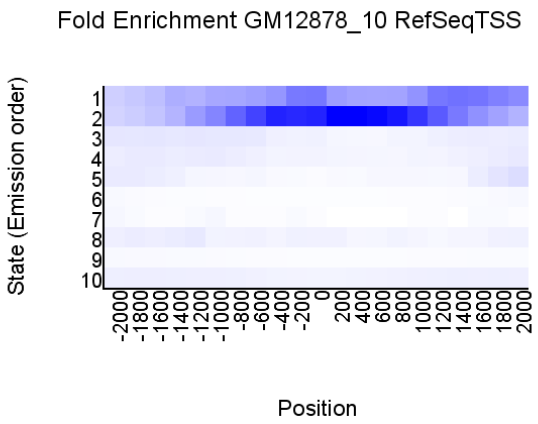
```
OverlapEnrichment [-a cell][-b binsize][-binres][-color r,g,b][-center]
[-colfields chromosome,start,end[,signal]][-e offsetend][-f coordlistfile][-m
labelmappingfile][-multicount][-posterior][-s offsetstart][-signal][-t
title][-uniformscale] inputsegment inputcoorddir outfileprefix
```



# Additional Commands

- NeighborhoodEnrichment – (re)computes enrichments of a segmentation around a set of anchor positions

```
usage NeighborhoodEnrichment [-a cell][-b binsize][-color r,g,b]
[-colfields chromosome,position[,optionalcol1|,optionalcol1,optionalcol2]]
[-l numleftintervals][-m labelmappingfile][-nostrand][-o anchoroffset]
[-posterior][-r numrightintervals][-s spacing][-signal][-t title]
inputsegment anchorpositions outfileprefix
```



# Additional Commands

- Reorder – reorders the states of the model

```
usage: Reorder [-color r,g,b][-f columnorderingfile][-holdcolumnorder]
[-i outfileID][-m labelmappingfile][-o stateorderingfile][-stateordering
emission|transition] inputmodel outputdir
```

# Summary

- Pre-computed ChromHMM chromatin state annotations available across over 100 cell/tissue types
- ChromHMM software available to run on your own data

http://compbio.mit.edu/ChromHMM

# Collaborators and Acknowledgements


- Manolis Kellis

**ENCODE consortium**

  – Brad Bernstein production group


**Roadmap Epigenomics consortium**


**Funding**

- NHGRI, NIH, NSF,  HHMI, Sloan Foundation