GS01 0163
Analysis of Microarray Data

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Lecture 9: Normalization, Affy, R, and Glass

- Revisiting Normalization in BioConductor
- R manipulations of AffyBatch
- Normalizing Project Normal

A Bioconductor Adventure...

Our goal – to reproduce the study of Bolstad et al. (2003) using the data supplied with BioConductor.

First, pull in the Affy functions and get the data

```
> library(affy);
> library(affydata);
> data(Dilution);
```

What steps are we trying to follow?

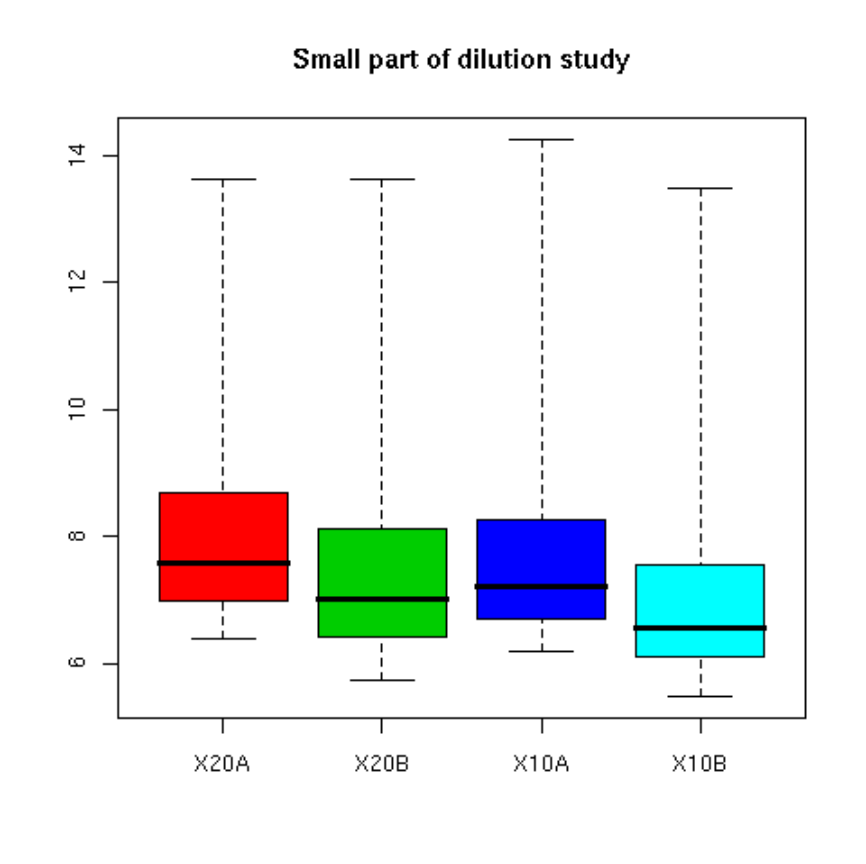
Starting with an AffyBatch object, presumably assembled straight from CEL files, we want to test the effects of different normalization methods on the stability of probeset measurements of the same stuff.

The steps:

Background correction
Normalization
PM correction
Summary Quantification

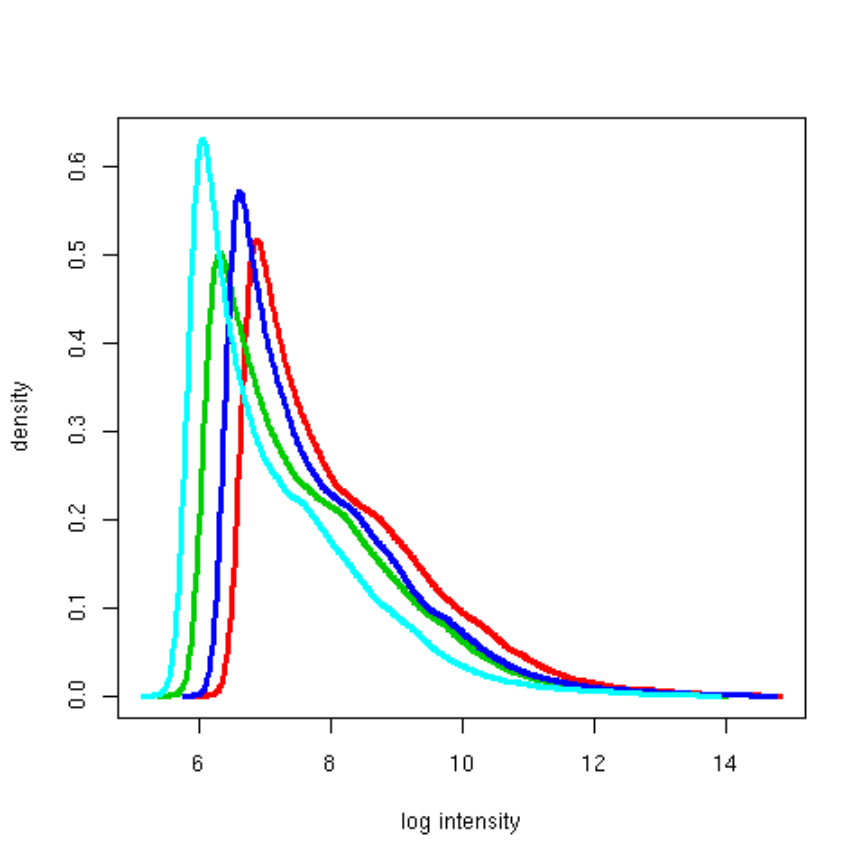
Monitor as we go!

Does this data need normalizing? (View 1)



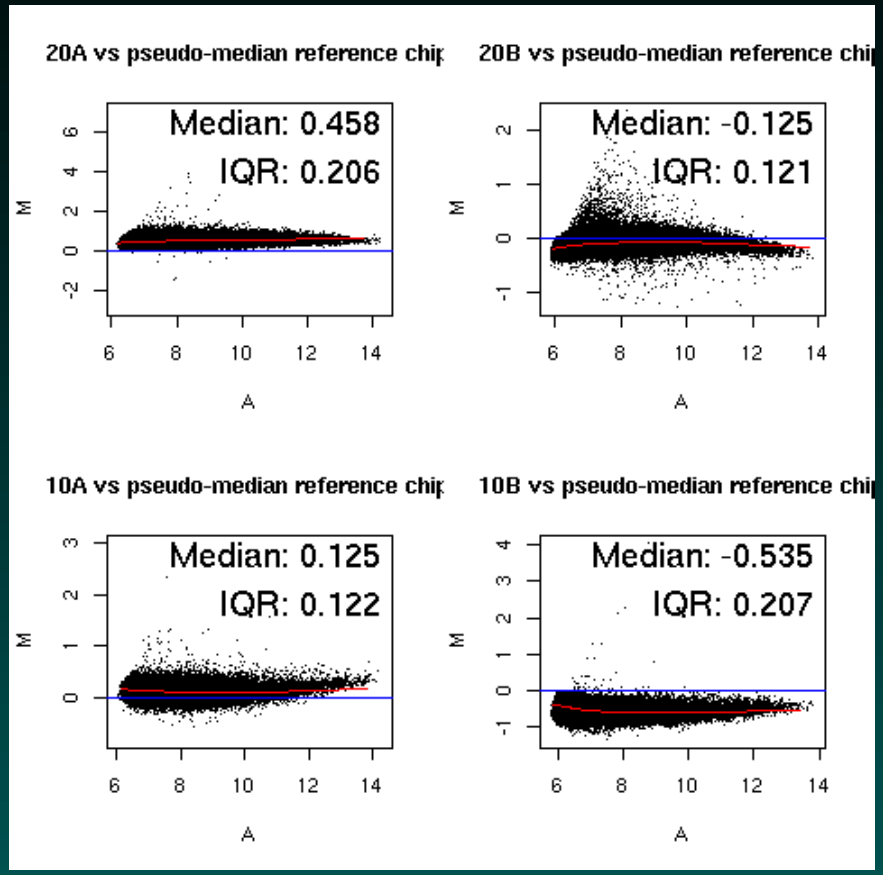

```
boxplot(Dilution); # shows log intensities!
dev.copy(png,file="boxplot1.png",col=2:5);
dev.off();
```

What about the densities? (View 2)




```
hist(Dilution,lty=1,col=2:5,lwd=3);
dev.copy(png,file="hist1.png");
dev.off();
```

and the MA plots?




```
par(mfrow=c(2,2));
MAplot(Dilution);
par(mfrow=c(1,1));
```

Look at all pairs?

```
mva.pairs(Dilution);
```

Look at all pairs?

```
mva.pairs(Dilution);


Error in log(x, base) : Non-numeric
  argument to mathematical function
> help(mva.pairs)
```

want to feed this function a matrix, with columns corresponding to arrays. Where are these numbers?

I can never remember...

Objects have slots!

```
> slotNames(Dilution)
[1] "cdfName"     "nrow"        "ncol"
[4] "assayData"   "phenoData"   "featureData"
[7] "experimentData" "annotation"   ".__classVersi
```

I can never remember...

Objects have slots!

```
> slotNames(Dilution)
[1] "cdfName"     "nrow"        "ncol"
[4] "assayData"   "phenoData"   "featureData"
[7] "experimentData" "annotation"   ".__classVersi
```

We can extract the numbers we want with `exprs`.

```
> length(exprs(Dilution))
[1] 1638400
> dim(exprs(Dilution))
[1] 409600 4
```

What's in the Slots?

```
Dilution@cdfName
[1] "HG_U95Av2"
> Dilution@nrow
[1] 640
> Dilution@ncol
[1] 640
> Dilution@phenoData
  sampleNames: 20A, 20B, 10A, 10B
  varLabels and varMetadata:
    liver: amount of liver RNA hybridized to array
    sn19: amount of central nervous system RNA hyb
    scanner: ID number of scanner used
> Dilution@experimentData
Experiment data
```

```
  Experimenter name: Gene Logic
  Laboratory: Gene Logic
  Contact information: 708 Quince Orchard Road
Gaithersburg, MD 20878
Telephone: 1.301.987.1700
Toll Free: 1.800.GENELOGIC (US and Canada)
Facsimile: 1.301.987.1701

  Title: Small part of dilution study
  URL: http://qolotus02.genelogic.com/datasets.ns
  PMIDs:

  Abstract: A 68 word abstract is available. Use
  Other:
```

```
> Dilution@annotation
[1] "hgu95av2"
> Dilution@.__classVersion__
        R   Biobase      eSet AffyBatch
  "2.5.0" "1.13.22"   "1.1.0"   "1.2.0"
```

Still haven't touched assayData or featureData...

What's in the Slots? (pt. 2)

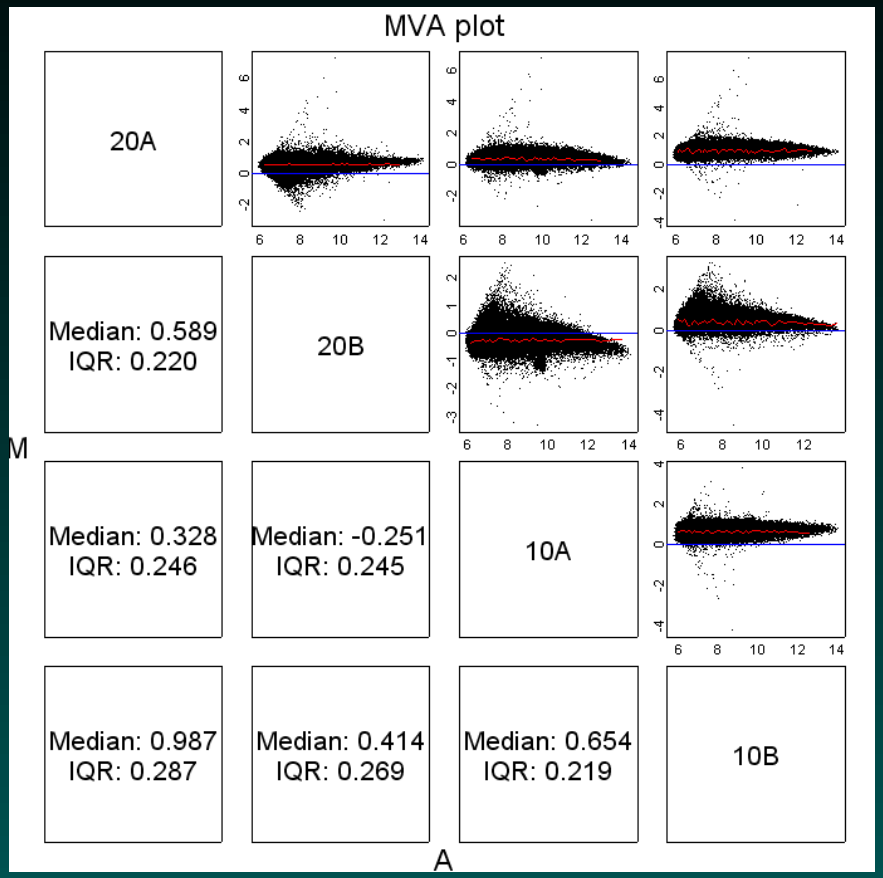
```
> Dilution@featureData
An object of class "Annotated Data Frame"
  featureNames: 1, 2, ..., 409600 (409600 total)
  varLabels and varMetadata: none
> class(Dilution@featureData)
[1] "AnnotatedDataFrame"
attr(,"package")
[1] "Biobase"
> slotNames(Dilution@featureData)
[1] "varMetadata" "data" "dimLabels" ".__classVers
> dim(Dilution@featureData@data)
[1] 409600      0
> rownames(Dilution@featureData@data)[10]
[1] "10"
```

What's in the Slots? (pt. 3)

```
> Dilution@assayData
$exprs
           20A     20B     10A     10B
1        149.0   112.0   129.0    60.0
...
24999    417.8   305.8   358.0   212.5
 [ reached getOption("max.print") -- omitted 3846
> class(Dilution@assayData)
[1] "list"
> length(Dilution@assayData)
[1] 1
> names(Dilution@assayData)
[1] "exprs"
> class(Dilution@assayData[[1]])
```

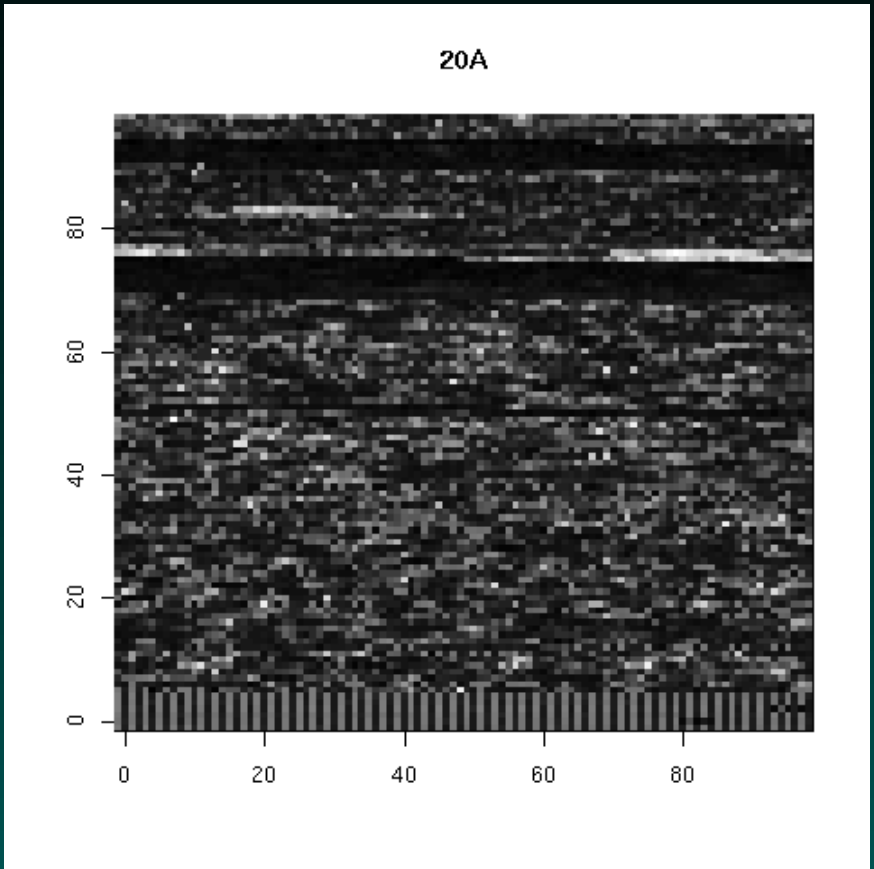
```
[1] "matrix"
> dim(Dilution@assayData[[1]])
[1] 409600      4
```

Back to M vs A




```
mva.pairs(exprs(Dilution));
```

Spatial Plots?




```
image(Dilution[,1],transfo=log2);
```

Ratios of Spatial Plots?

```
image(matrix(exprs(Dilution[,1]),
             nrow=nrow(Dilution),
             ncol=ncol(Dilution)),
      transfo=log2);
```

Ratios of Spatial Plots?

```
image(matrix(exprs(Dilution[,1]),
             nrow=nrow(Dilution),
             ncol=ncol(Dilution)),
      transfo=log2);
```

parameter “transfo” can’t be set in high-level plot() function.

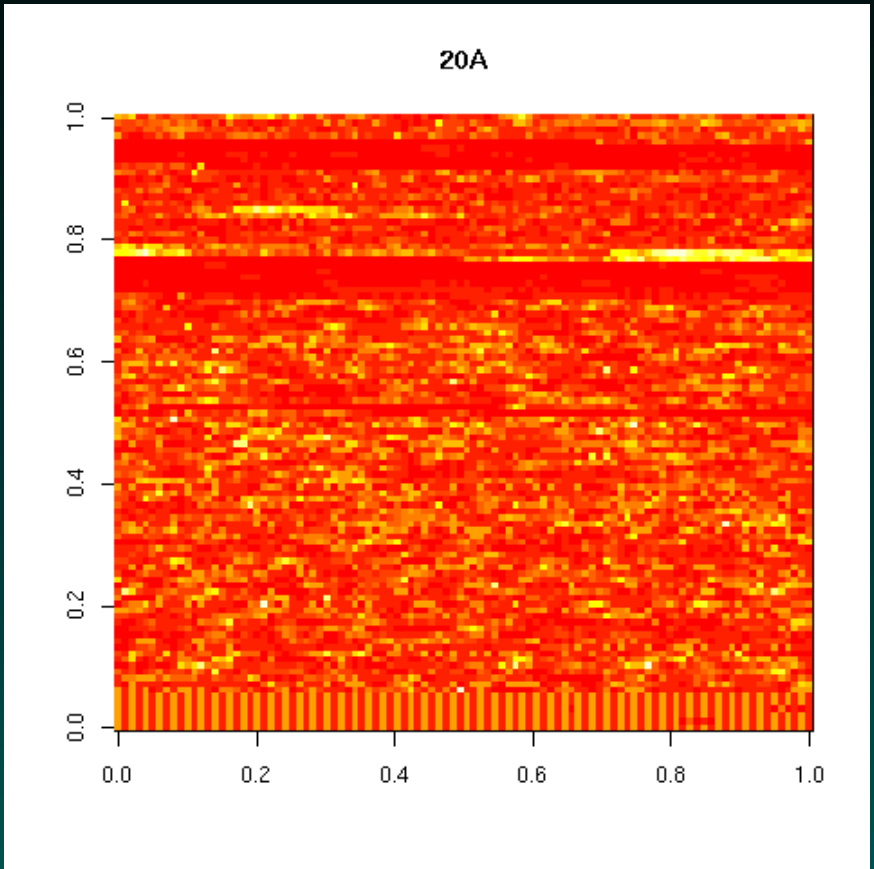
Ratios of Spatial Plots?

```
image(matrix(exprs(Dilution[,1]),
             nrow=nrow(Dilution),
             ncol=ncol(Dilution)),
      transfo=log2);
```

parameter “transfo” can’t be set in high-level plot() function.

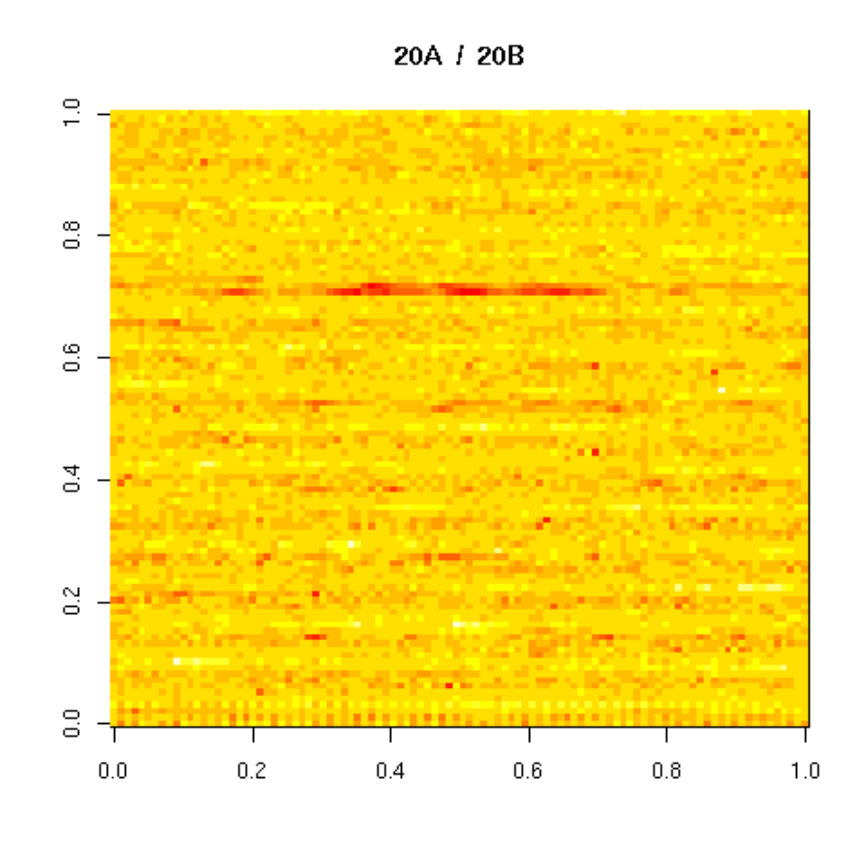
```
image(log2(matrix(
   exprs(Dilution[,1]),...
```

Spatial Plot 1




```
image(log2(matrix(exprs(Dilution[,1]),..)),
      main=sampleNames(Dilution[,1]));
```

Ratio Plot 1 (problem: fake geometry)




```
image(log2(matrix(exprs(Dilution[,1])/
                  exprs(Dilution[,2]),..)),
      main=paste(sampleNames(Dilution[,1]),...));
```

Ok, start processing. BG first

```
Dilution.bg <- bg.correct.rma(Dilution);
```

Did this change things?

```
hist(Dilution.bg, lty=1, col=2:5, lwd=3)
```

Ok, start processing. BG first

```
Dilution.bg <- bg.correct.rma(Dilution);
```

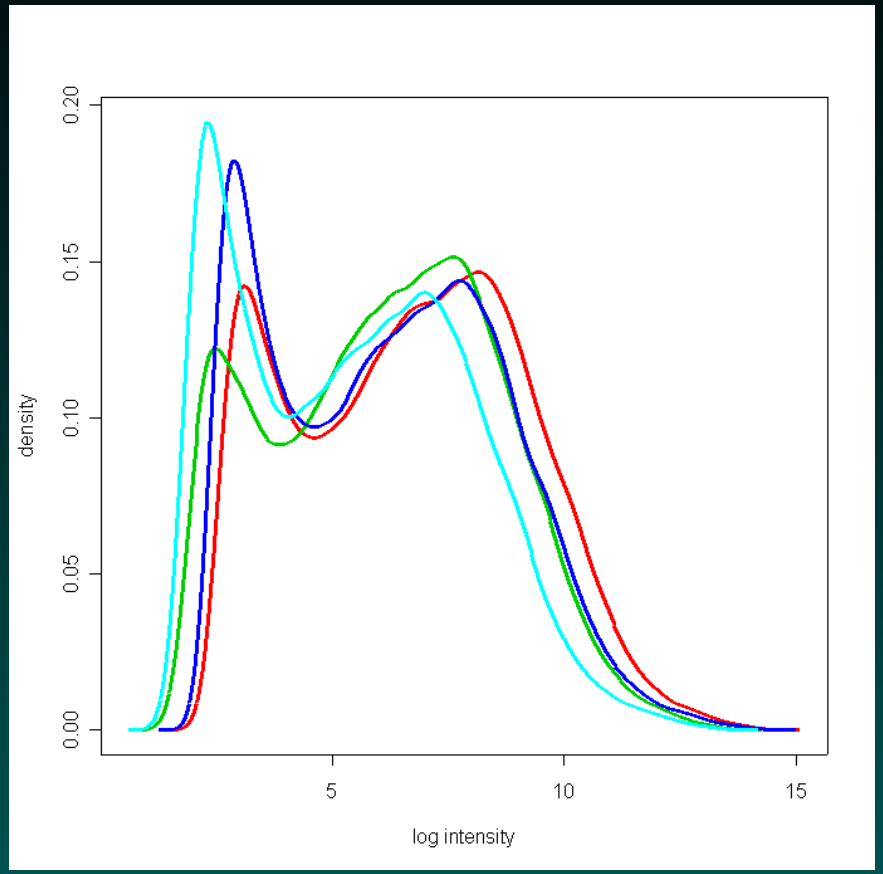
Did this change things?

```
hist(Dilution.bg, lty=1, col=2:5, lwd=3)
```

Let's also try it a different way to make sure...

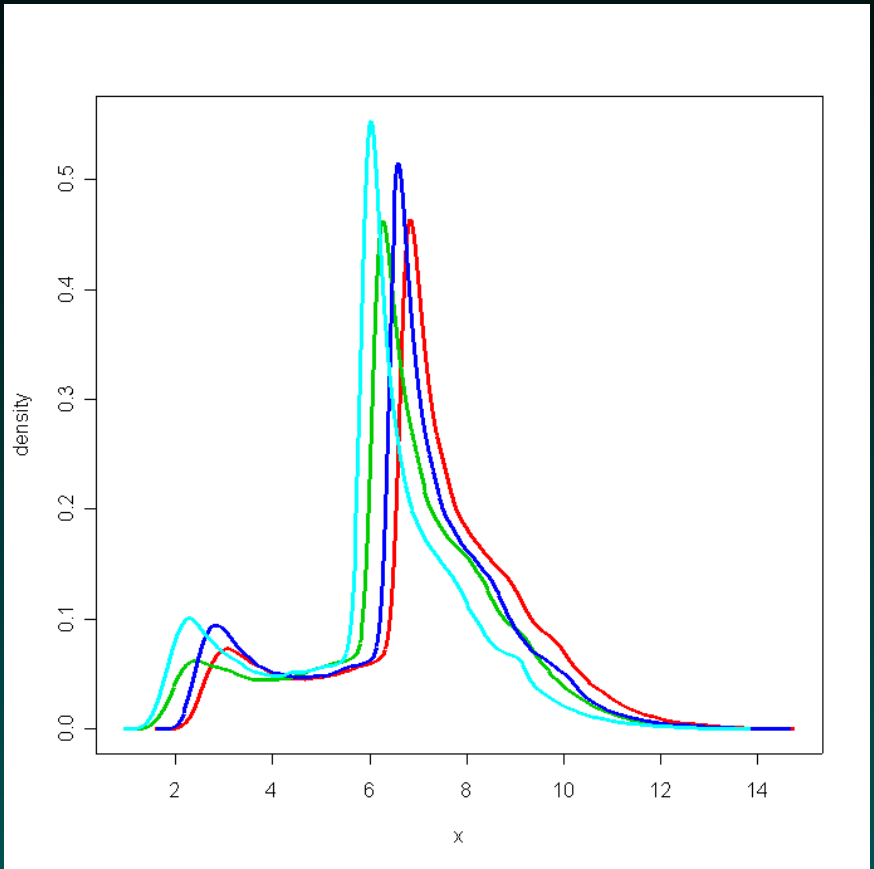
```
plotDensity(log2(exprs(Dilution.bg)),
            lty=1,col=2:5,lwd=3)
```

Picture 1 After BG



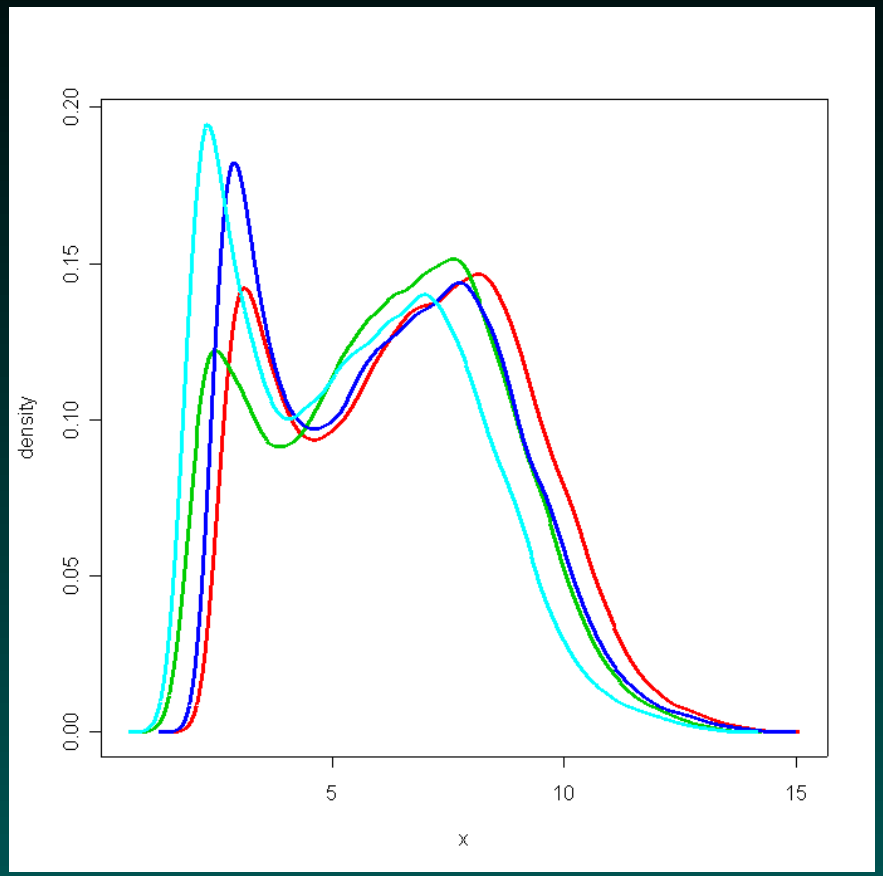

```
hist(Dilution.bg, lty=1, col=2:5, lwd=3)
```

Picture 2 After BG



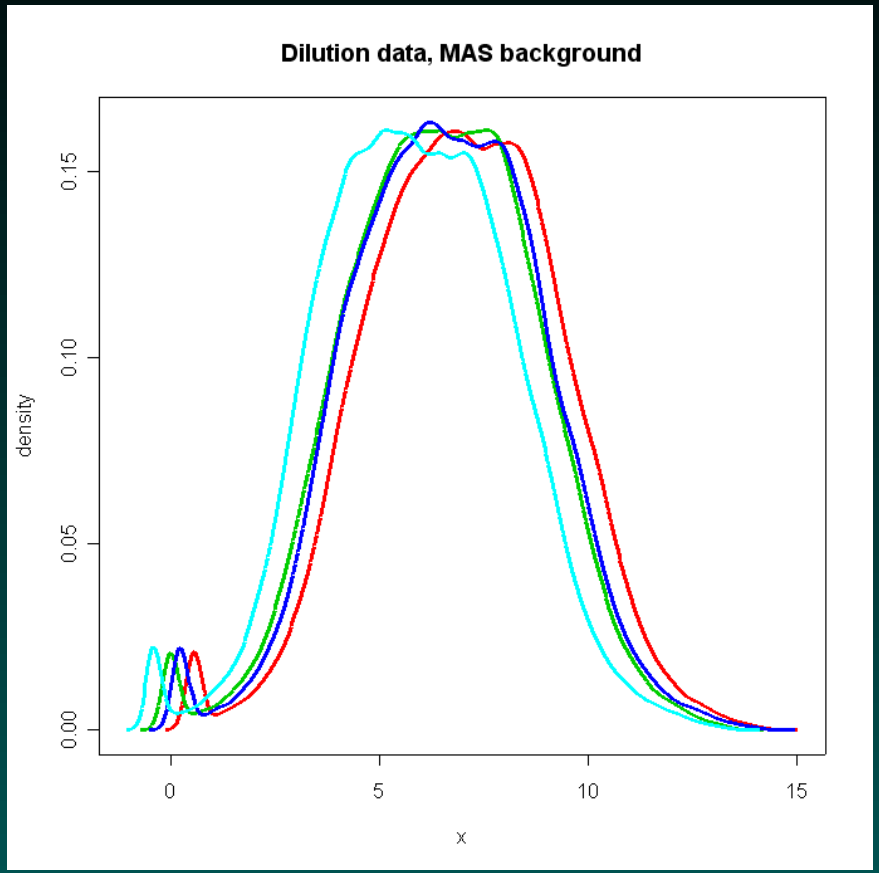

```
plotDensity(log2(exprs(Dilution.bg)),
    lty=1,col=2:5,lwd=3)
```

Picture 2 (try 2) After BG




```
plotDensity(log2(pm(Dilution.bg)),
    lty=1,col=2:5,lwd=3)
```

Is Background a Big Deal?




```
Dilution.bg <- bg.correct.mas(Dilution);
hist(Dilution.bg, lty=1, col=2:5, lwd=3);
title(main="Dilution data, MAS background");
```

and now we normalize!

This is where the differences come in. We can invoke

normalize.AffyBatch.constant
normalize.AffyBatch.contrasts
normalize.AffyBatch.invariantset
normalize.AffyBatch.quantiles

or, of course, we can have `expresso`

Expresso, no normalization

```
eset0 <- expresso(Dilution,
            bgcorrect.method="rma",
            normalize=FALSE,
            pmcorrect.method="pmonly",
            summary.method="medianpolish");
```

Now at this point, `eset0` is an ExpressionSet object; the dimensions of the matrix extracted by `exprs` have changed as we have shifted from features (probes) to probesets.

What Does an ExpressionSet Have?

```
> slotNames(eset0)
[1] "assayData"     "phenoData"     "featureData"
[4] "experimentData"    "annotation"
[6] ".__classVersion__"
> rownames(eset0@featureData@data)[10]
[1] "1009_at"
> eset0@assayData
<environment: 0x1cb8f904>
> ls(eset0@assayData)
[1] "exprs"     "se.exprs"
> dim(get("exprs",eset0@assayData))
[1] 12625     4
```

Checking the Environment

```
> myEnv <- new("environment")
> frogs <- rnorm(5)
> assign("frogs",frogs,envir=myEnv)
> ls(myEnv)
[1] "frogs"
```

Environments are useful things. Basically, they're R's answer to "pass by reference" instead of "pass by value".

What do we want?

The mean and variance of the probeset measurements gene by gene, to describe the behavior of this normalization method.

```
> dim(exprs(eset0))
[1] 12625 4
> eset0.mu <- apply(exprs(eset0),1,"mean");
> eset0.var <- apply(exprs(eset0),1,"var");
```

Now we want another method to compare to.

Constant normalization: choosing baseline

find the “middle behavior” chip

Constant normalization: choosing baseline

find the “middle behavior” chip

```
> apply(exprs(Dilution),2,"median");
20A 20B 10A 10B
188 127 149  94

eset1 <- expresso(Dilution,
    bgcorrect.method = "rma",
    normalize.method = "constant",
    normalize.param  = list(refindex=3),
    pmcorrect.method = "pmonly",
    summary.method   = "medianpolish");

> eset1.mu <- apply(exprs(eset1),1,"mean");
> eset1.var <- apply(exprs(eset1),1,"var");
```

So, how do we compute MA plots here?

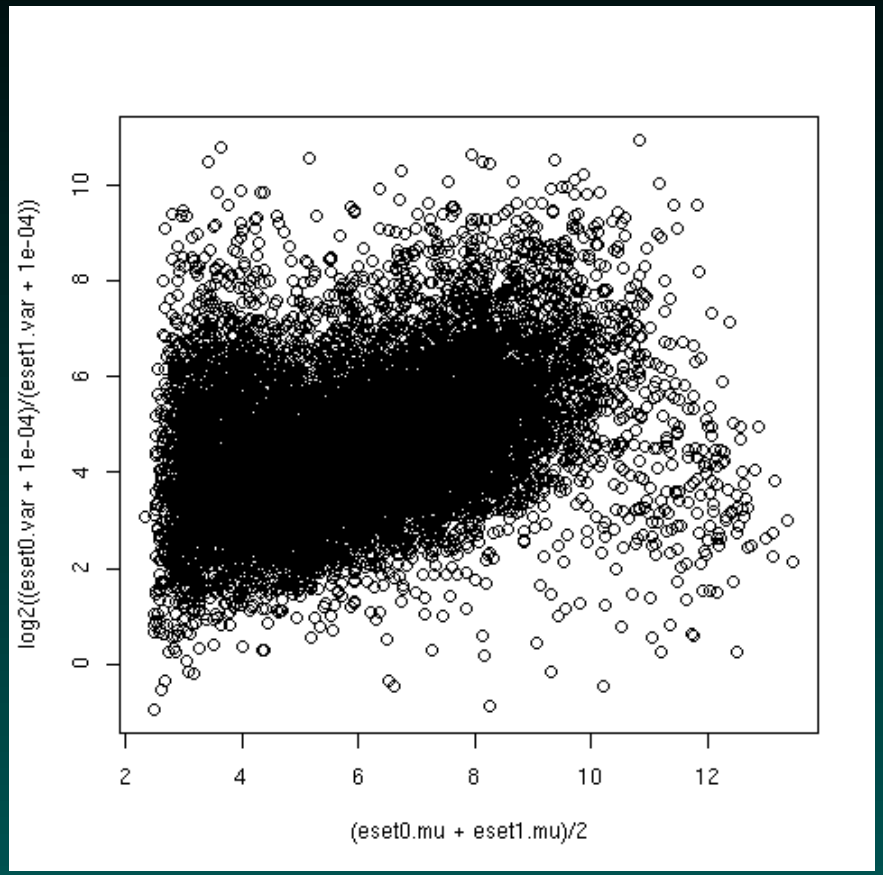
Normally, we are plotting the results from one chip against that from another. Here, we are working with two sets of results from the same chips, just using different methods for quantification.

```
A1 <- (eset0.mu + eset1.mu)/2;
M1 <- (eset0.mu - eset1.mu)/2; # not quite.
M2 <- (eset0.var / eset1.var); # still not quite.
M3 <- log2(eset0.var / eset1.var);
```

This may still be driven by outliers. Tweak.

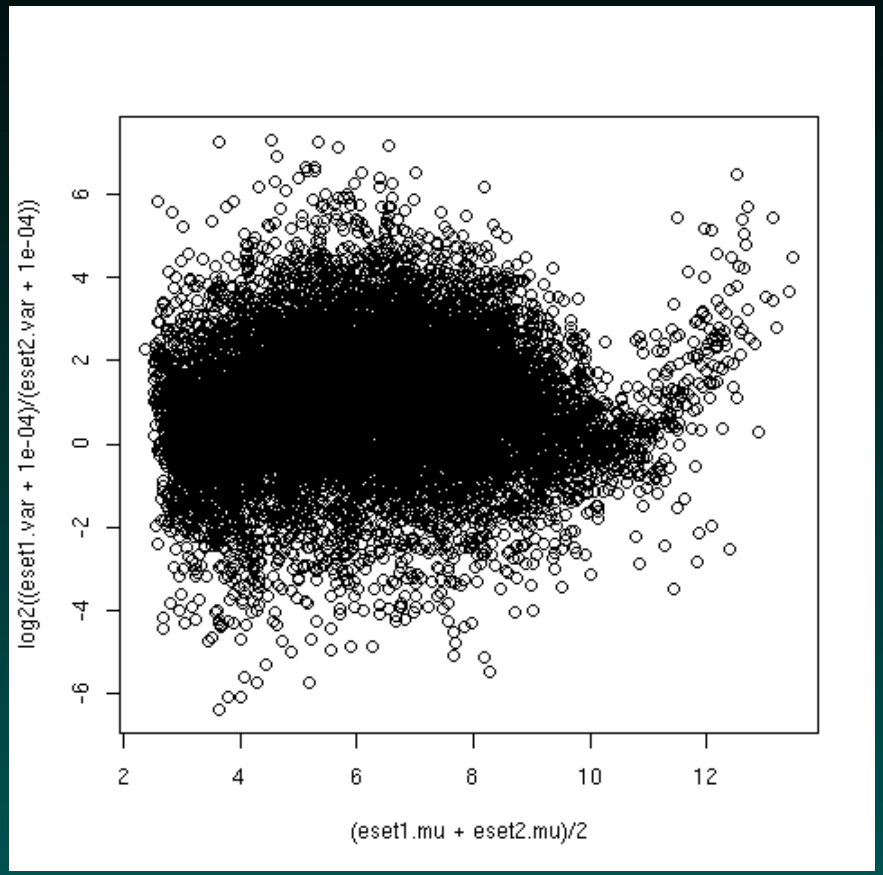
```
d0 <- 0.0001;
M4 <- log2((eset0.var + d0)/(eset1.var + d0));
```

Dilution: “none” against “scaling”



Here, 12615 times out of 12625, constant scaling gives lower variability. Mean log diff: 4.65

Dilution: “scaling” against “quantiles”



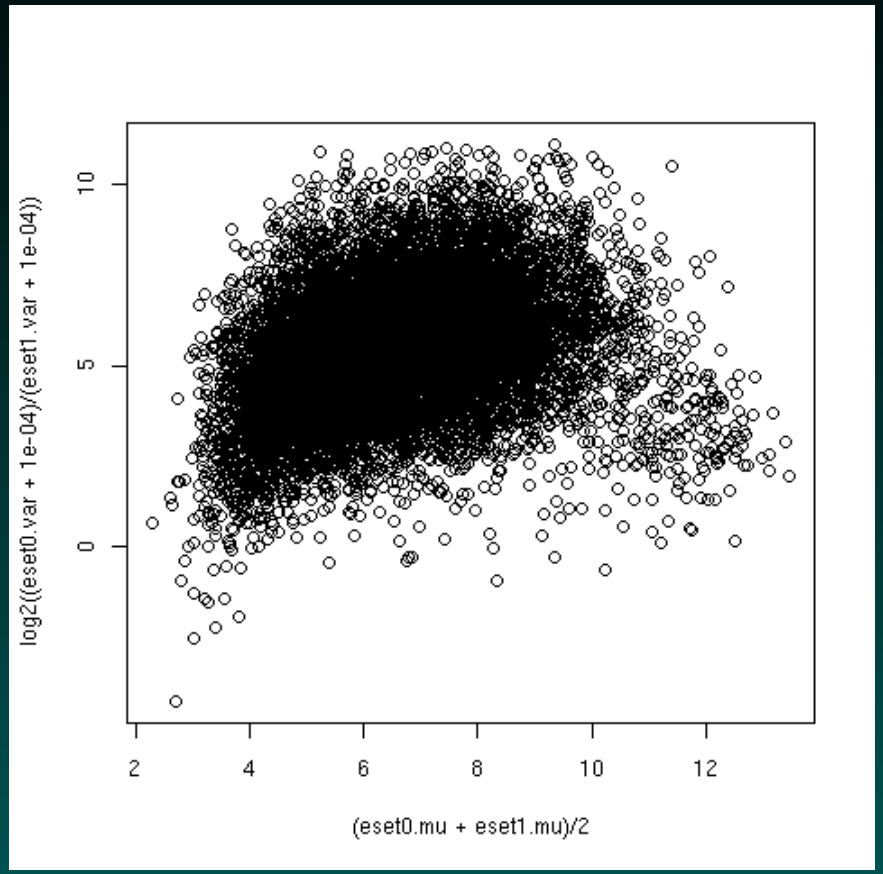
Here, 9477 times out of 12625, quantile scaling gives lower variability. Mean log diff: 0.98

What didn't they do?

Our comparison of normalization methods here focused on reducing variability, and it assumed that a particular type of background correction (rma) and summarization (median polish) had been employed.

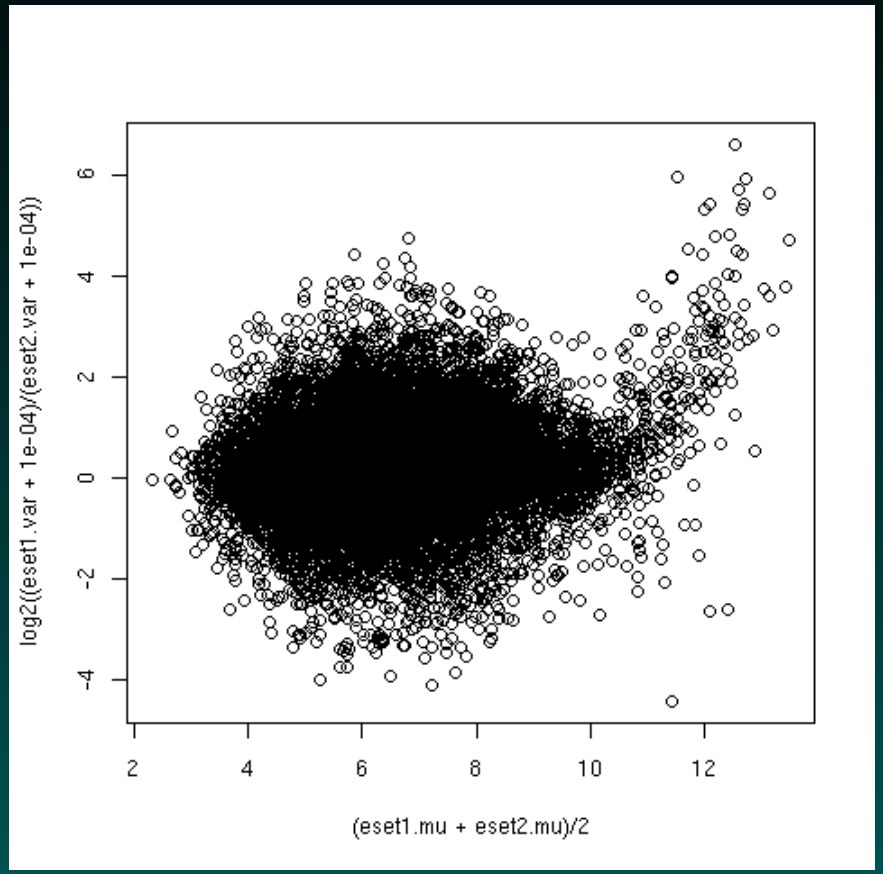
But we saw that different background correction methods led to different shapes in the distributions of probe intensities. If we use "mas" as the background subtraction method, are the differences between the normalization methods still as stark?

Dilution: “none” against “scaling”, MAS BG



Here, 12600 times out of 12625, constant scaling gives lower variability. Mean log diff: 5.40

Dilution: “scaling” vs “quantiles”, MAS BG



Here, 7937 times out of 12625, quantile scaling gives lower variability. Mean log diff: 0.265

Normalizing on Glass?

Main difference is two-color setup

Some general recommendations:

Normalize channels to each other first, then normalize log ratios across chips.

Do dye swaps.

MA plots, loess fits, and pictures.

Project Normal: A Cautionary Tale

Pritchard, Hsu, Delrow and Nelson
Project Normal: Defining Normal Variance in Mouse Gene Expression
PNAS **98** (2001), 13266-13271.

Data set used for the third annual Critical Analysis of Microarray Data (CAMDA 2002)

Pritchard et al.'s Initial Goals

The goal of many microarray studies is to identify genes that are "differentially expressed".

Relative to what?

Differences larger in scale than those that would be encountered due to "normal" or technical variation.

Try to assess the fraction of genes exhibiting a large mouse-to-mouse heterogeneity in the absence of structure.

Pritchard et al.'s Experimental Design

Eighteen Samples

- Six C57BL6 male mice
- Three organs: kidney, liver, testis

Reference Material

- Pool all eighteen mouse organs

Replicate microarray experiments using two-color fluorescence with common reference and dye swaps

- Four experiments per mouse organ, 2 each dye

Pritchard et al.'s Analysis

Print-tip specific intensity dependent loess normalization

Perform F-tests on log(Exp/Ref) for each gene to see if mouse-to-mouse variance exceeds the array-to-array variance

The Data Supplied

Images

One quantification file each for kidney, liver and testis.

```
CDNA ID, Cluster ID, Title,
Block, Column, Row

F635 Median M1K3_1, B635 Median M1K3_1
F532 Median M1K3_1, B532 Median M1K3_1
```

Mouse 1, Kidney Sample in Cy3 channel, first replicate.

Why Coombes and Baggerly Got Involved

All in all, the analysis described looks pretty good. F-tests on log ratios seem reasonable, and the preprocessing steps they used are fairly standard. Furthermore, the images looked fairly clean.

Why Coombes and Baggerly Got Involved

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"Fairly standard" $\neq$ correct

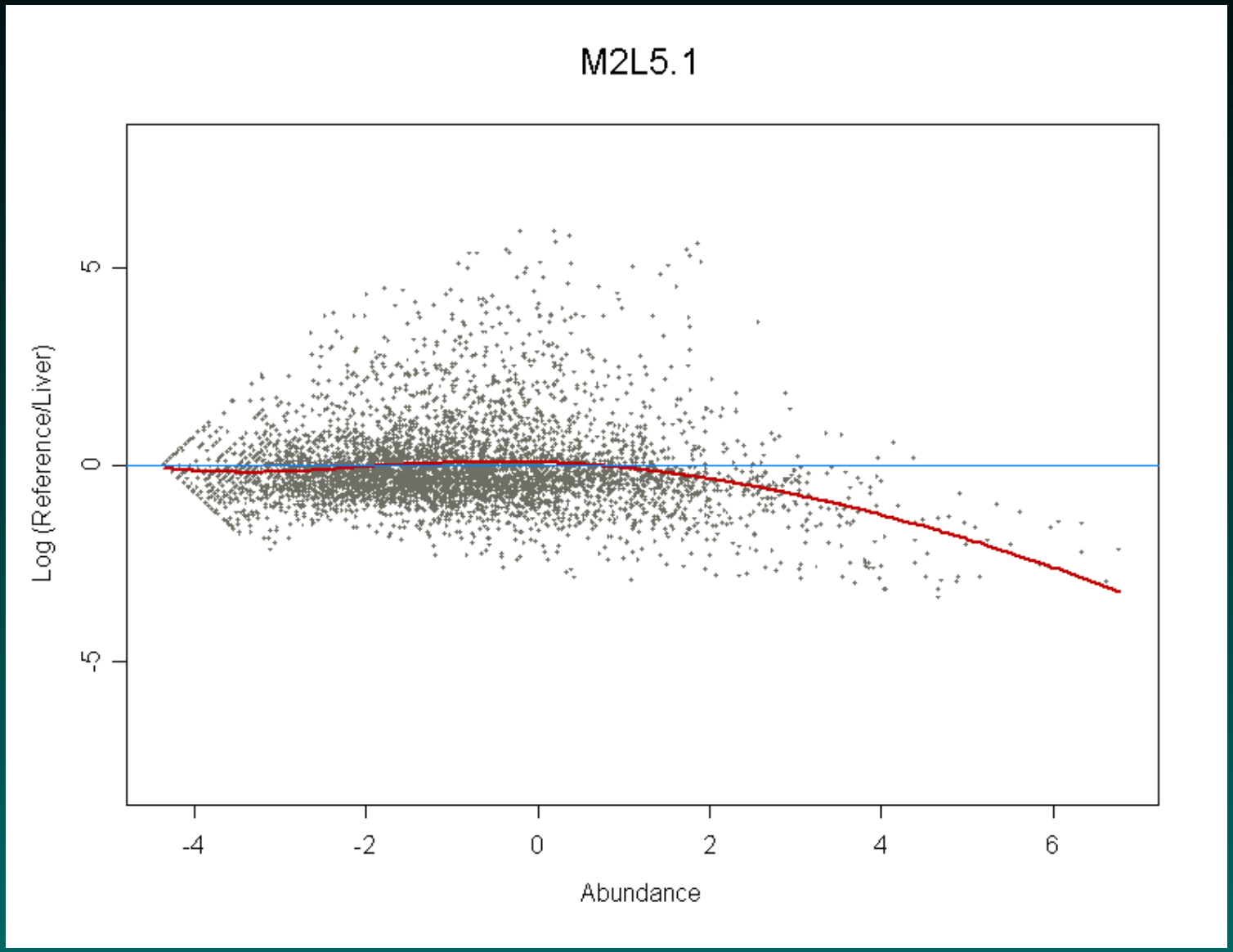
Why Coombes and Baggerly Got Involved

All in all, the analysis described looks pretty good. F-tests on log ratios seem reasonable, and the preprocessing steps they used are fairly standard. Furthermore, the images looked fairly clean.

"Fairly standard" $\neq$ correct

For this data, we think that loess normalization is incorrect.

What Loess Looks Like for 1 Array



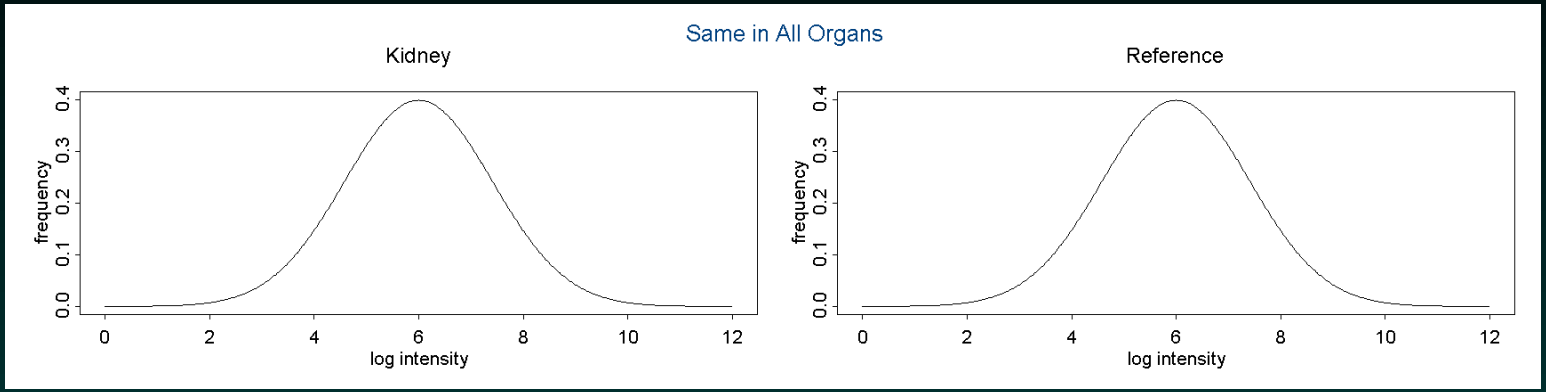
Why Loess Normalization?

Most normalization methods assume:

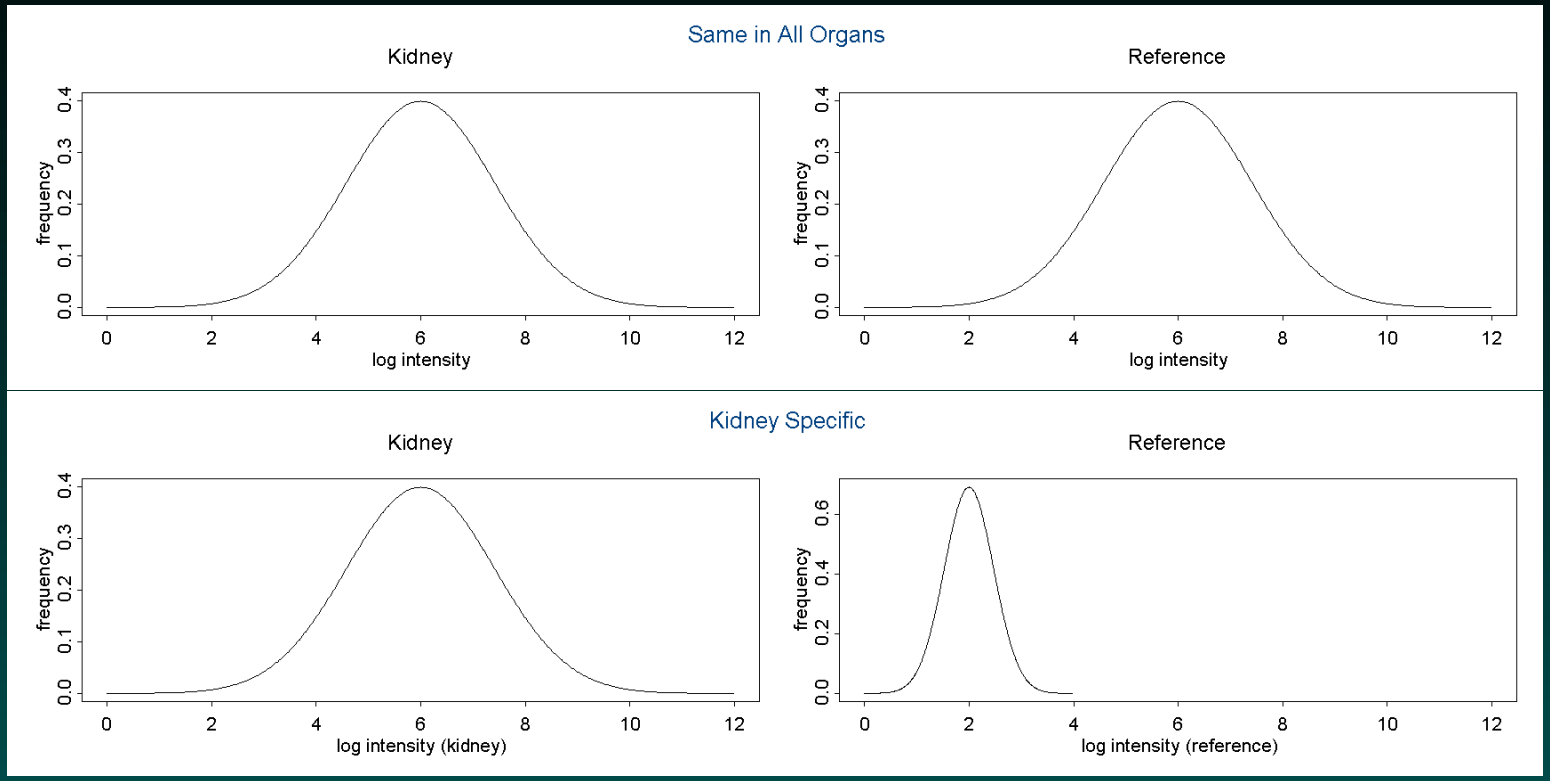
- Distributions of intensities are the same in the two channels
- Most genes do not change expression
- The number of overexpressed genes is about the same as the number of underexpressed genes

Loess normalization tries to force the distributions in the two channels to match, believing that differences are attributable to technology.

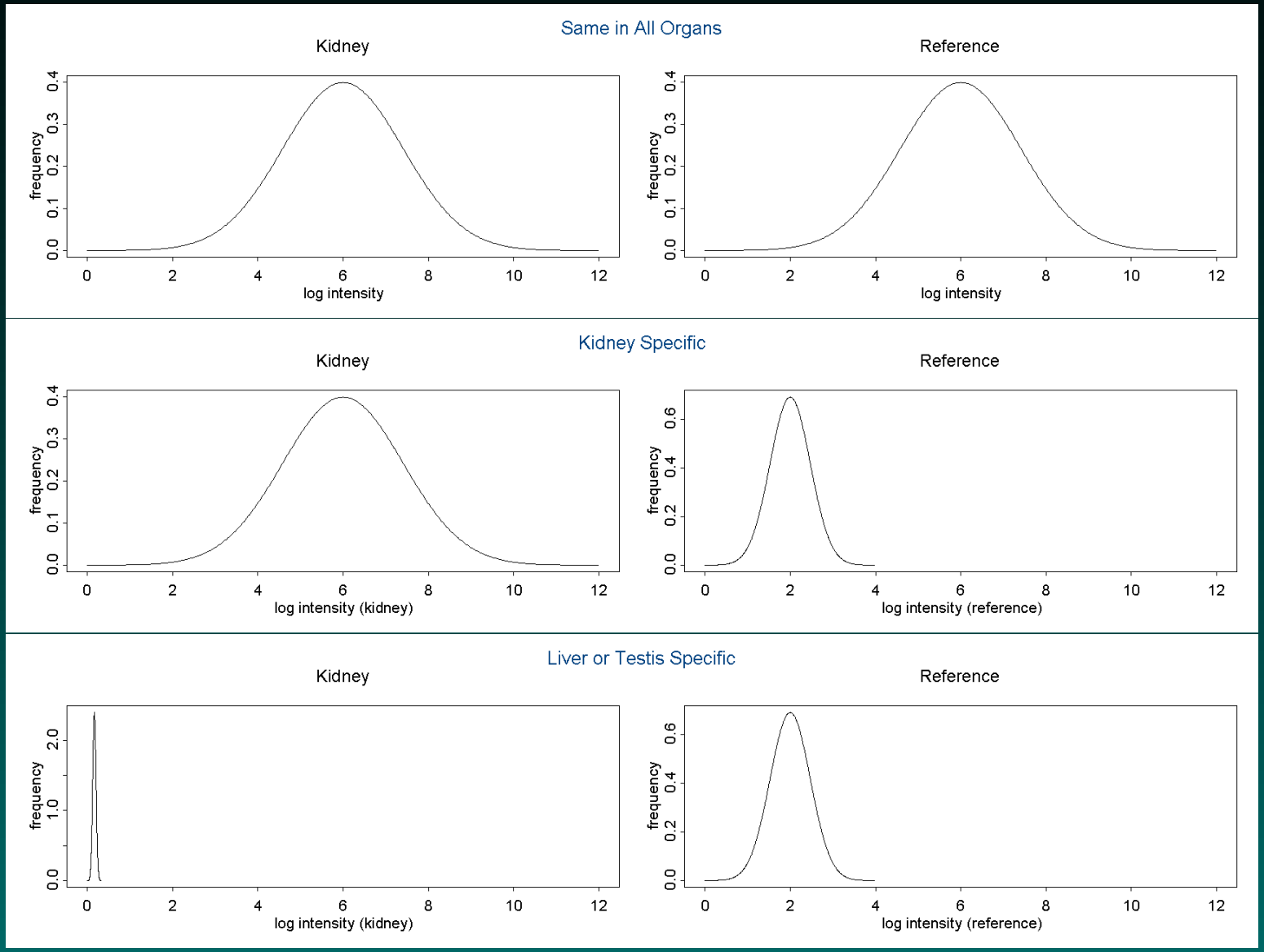
Why Coombes and Baggerly Think It's Wrong



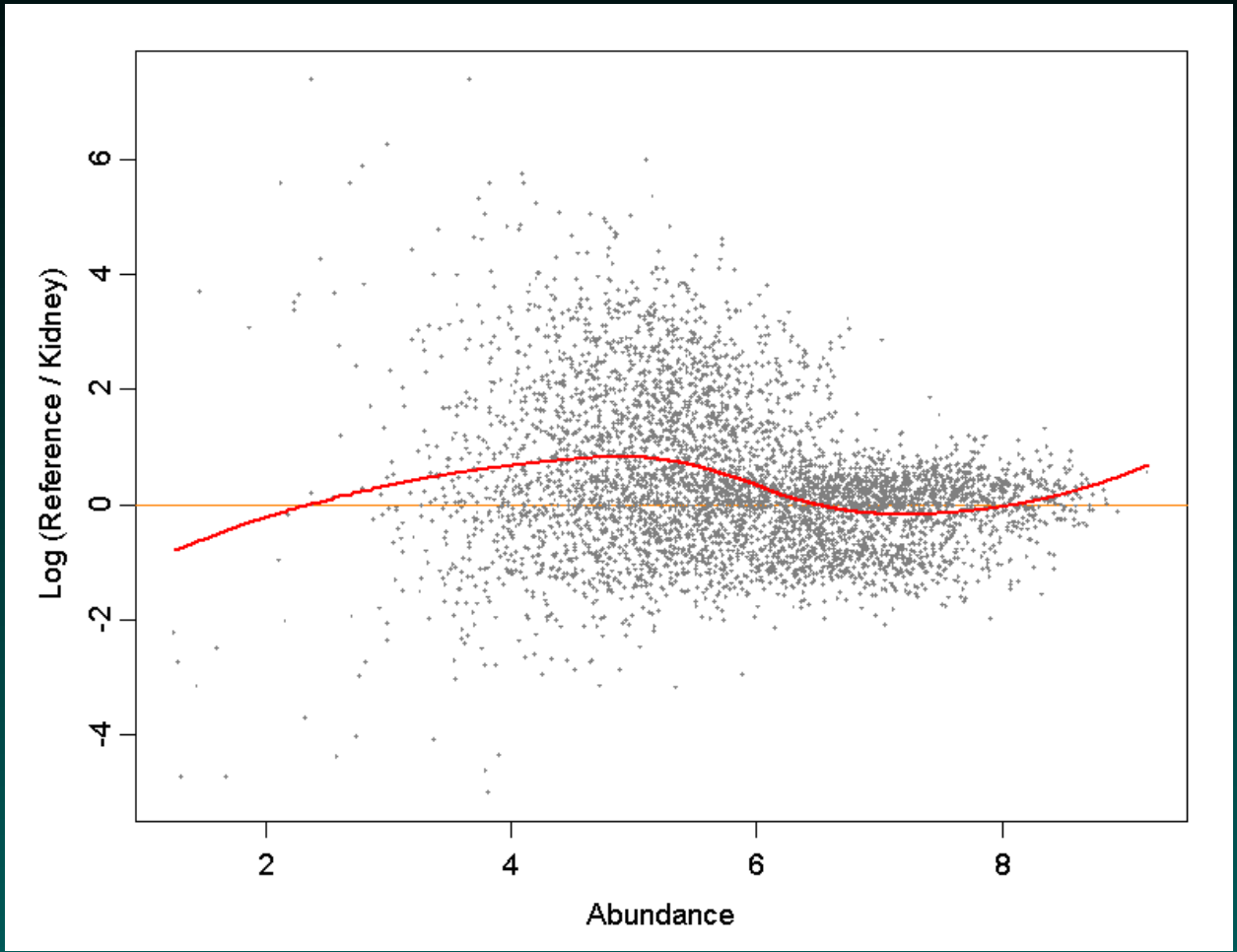
Why Coombes and Baggerly Think It's Wrong



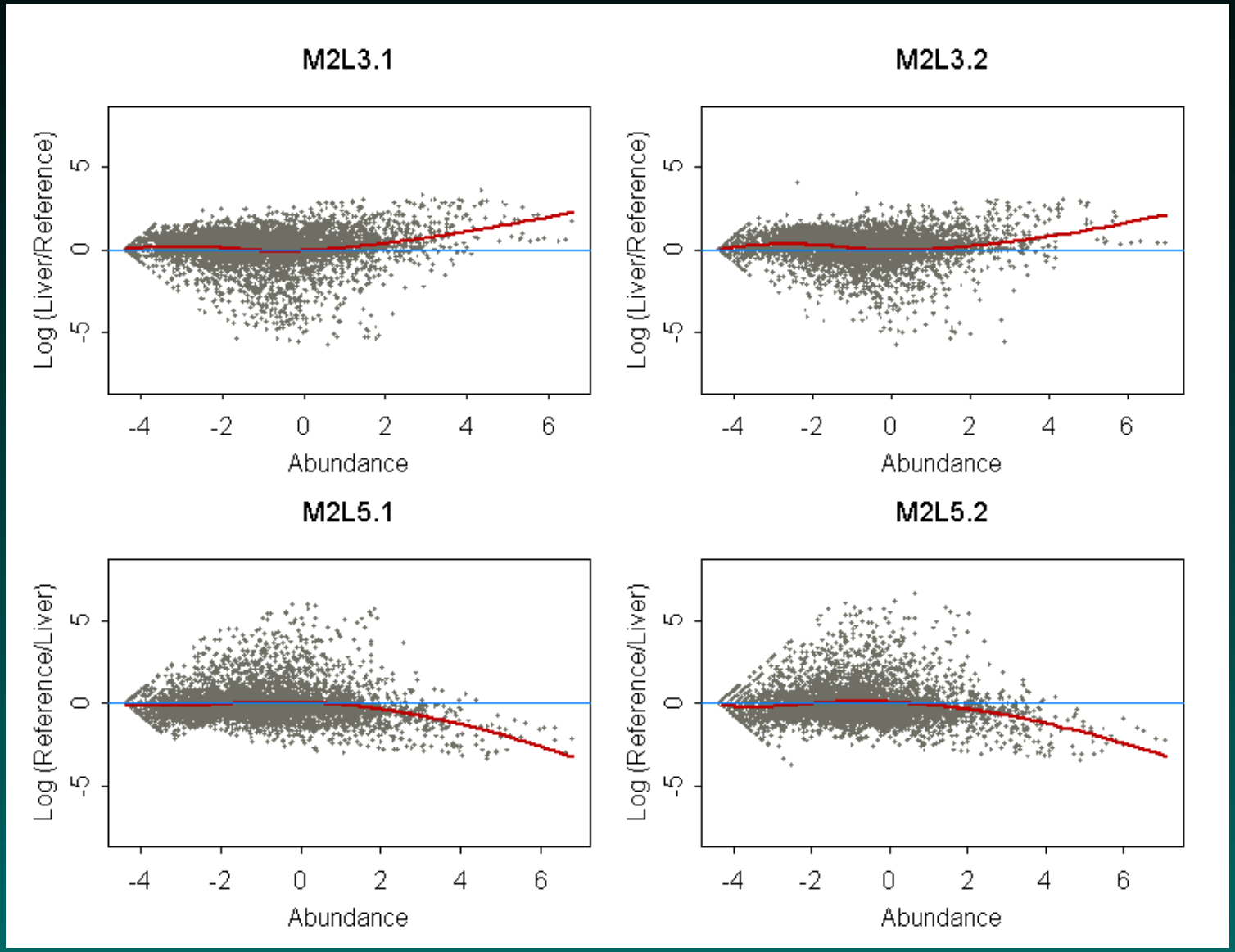
Why Coombes and Baggerly Think It's Wrong



Simulated Data Using Their Approach



Were They Right? Checking the Dye Swaps



Interpretation

- Distributions of intensities are different in the two channels
- Difference is NOT caused by arrays, dyes, or technology
- Difference is inherent in the choice of reference material

So, How Do We Normalize This Data?

Normalize channels separately

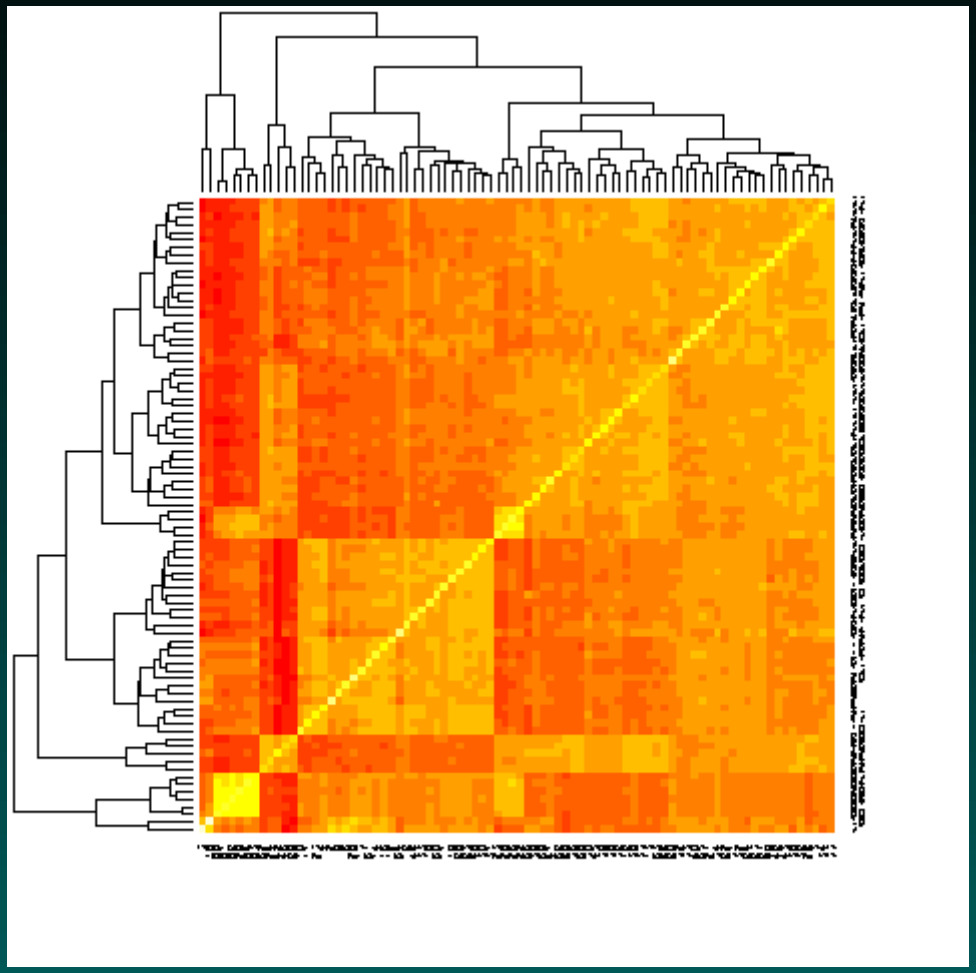
Divide by 75^{th} percentile (magic)

Multiply by 10 (arbitrary, equalizes scale)

Set threshold at 0.5 (more magic)

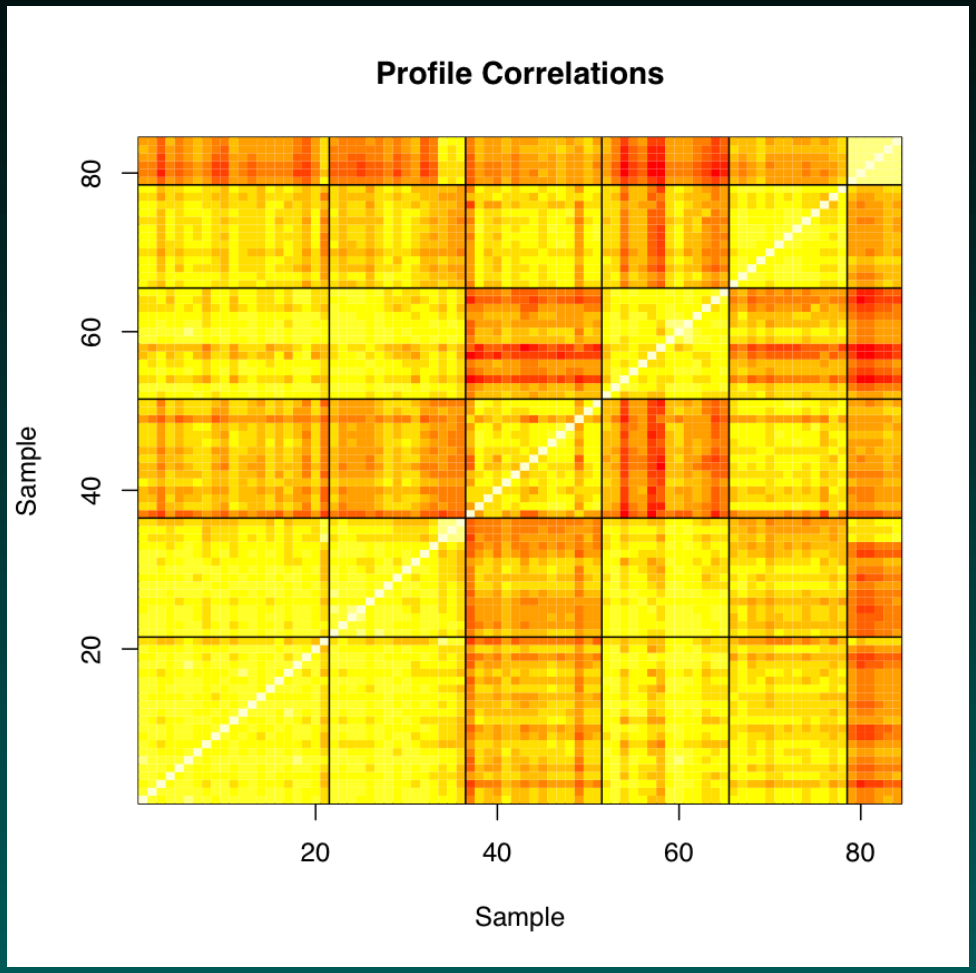
Log transform

Normalization Isn't Perfect (1)



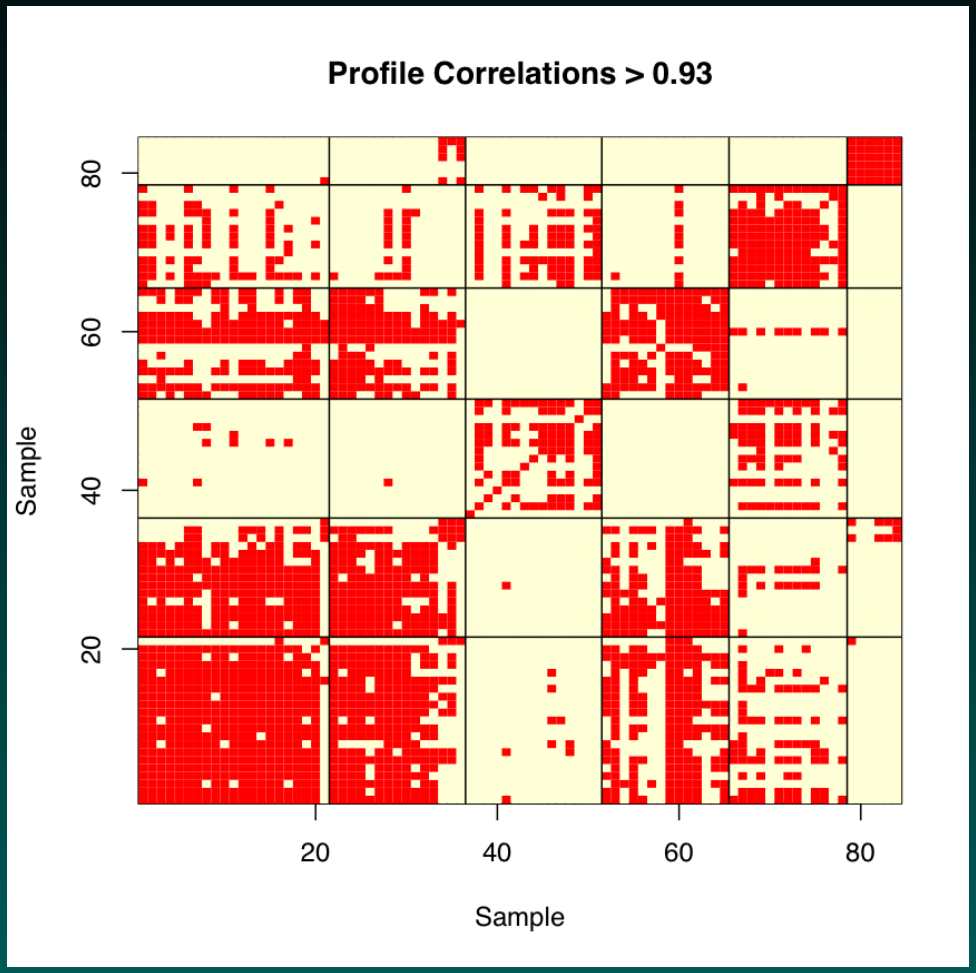
Same tissue type, all with RMA.

Normalization Isn't Perfect (2)



Correlations, with run date dividers.

Normalization Isn't Perfect (3)



Correlations, high values shown.