



UNIVERSITY OF
GEORGIA

College of Agricultural &
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SNP effects and weights from ssGBLUP using BLUPF90

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UGA Team – 08/2019

SNP effect and weights in ssGBLUP

$$\begin{bmatrix} \mathbf{X}'\mathbf{X} & \mathbf{X}'\mathbf{W} \\ \mathbf{W}'\mathbf{X} & \mathbf{W}'\mathbf{W} + \mathbf{H}^{-1}\lambda \end{bmatrix} \begin{bmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{u}} \end{bmatrix} = \begin{bmatrix} \mathbf{X}'\mathbf{y} \\ \mathbf{Z}'\mathbf{y} \end{bmatrix}$$

$$\hat{\mathbf{a}} = \sigma_u^{-2} \sigma_a^2 \mathbf{D} \mathbf{Z}' \mathbf{G}^{-1} \hat{\mathbf{u}}$$

Matrix of SNP weights
 Matrix of SNP content
 Genomic relationship matrix

a) Quadratic SNP weights (Falconer & Mackay, 1996)

$$d_i = \hat{a}_i^2 2p_i(1 - p_i) \quad \text{Default}$$

b) Nonlinear A SNP weights (VanRaden, 2008)

$$d_i = 1.125 \frac{|\hat{a}_i|}{sd(\hat{\mathbf{a}})}^{-2}$$

SNP effect in ssGBLUP

$$\begin{bmatrix} \mathbf{X}'\mathbf{X} & \mathbf{X}'\mathbf{W} \\ \mathbf{W}'\mathbf{X} & \mathbf{W}'\mathbf{W} + \mathbf{H}^{-1}\lambda \end{bmatrix} \begin{bmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{u}} \end{bmatrix} = \begin{bmatrix} \mathbf{X}'\mathbf{y} \\ \mathbf{Z}'\mathbf{y} \end{bmatrix}$$

$$\hat{\mathbf{a}} = \sigma_u^{-2} \sigma_a^2 \mathbf{D} \mathbf{Z}' \mathbf{G}^{-1} \hat{\mathbf{u}}$$

Matrix of SNP weights

Matrix of SNP content

Genomic relationship matrix

- What else to do with weights SNP effects?

1) Indirect predictions for animals not included in the evaluation

$$\mathbf{D}\mathbf{G}\mathbf{V} = \mathbf{Z}\hat{\mathbf{a}}$$

Weights or variances for SNP in ssGBLUP

- What to do with weights or variance for SNP?
 - 1) Single-step Genome-Wide Association Studies - ssGWAS
proportion of σ_u^2 explained by SNP
 - 2) Weighted single-step GBLUP - WssGBLUP
different σ_a^2 for each SNP when constructing **G**

Weighted single-step GBLUP - WssGBLUP

Weights for SNP in ssGBLUP

- ssGBLUP
 - Same weights for SNP

$$G = \frac{ZZ'}{2 \sum p_i(1-p_i)}$$

- WssGBLUP
 - Different weights for SNP

$$G = \frac{ZDZ'}{2 \sum p_i(1-p_i)}$$

- Weights may increase accuracy of GEBV
- If SNPs explain high %variance

SNP weighting in ssGBLUP: WssGBLUP

• Wang et al. (2012):

1) Set $\mathbf{D}_t = \mathbf{I}$ and $\mathbf{G}_t = \frac{\mathbf{ZDZ}'}{2 \sum p_i(1-p_i)}$

2) Compute GEBV using ssGBLUP approach

3) Compute SNP effects as $\hat{\mathbf{a}} = \lambda \mathbf{D} \mathbf{Z}' \mathbf{G}^{-1} \widehat{\mathbf{GEBV}}$

4) Calculate SNP weight

5) Normalize $\mathbf{D}_{(t+1)}$

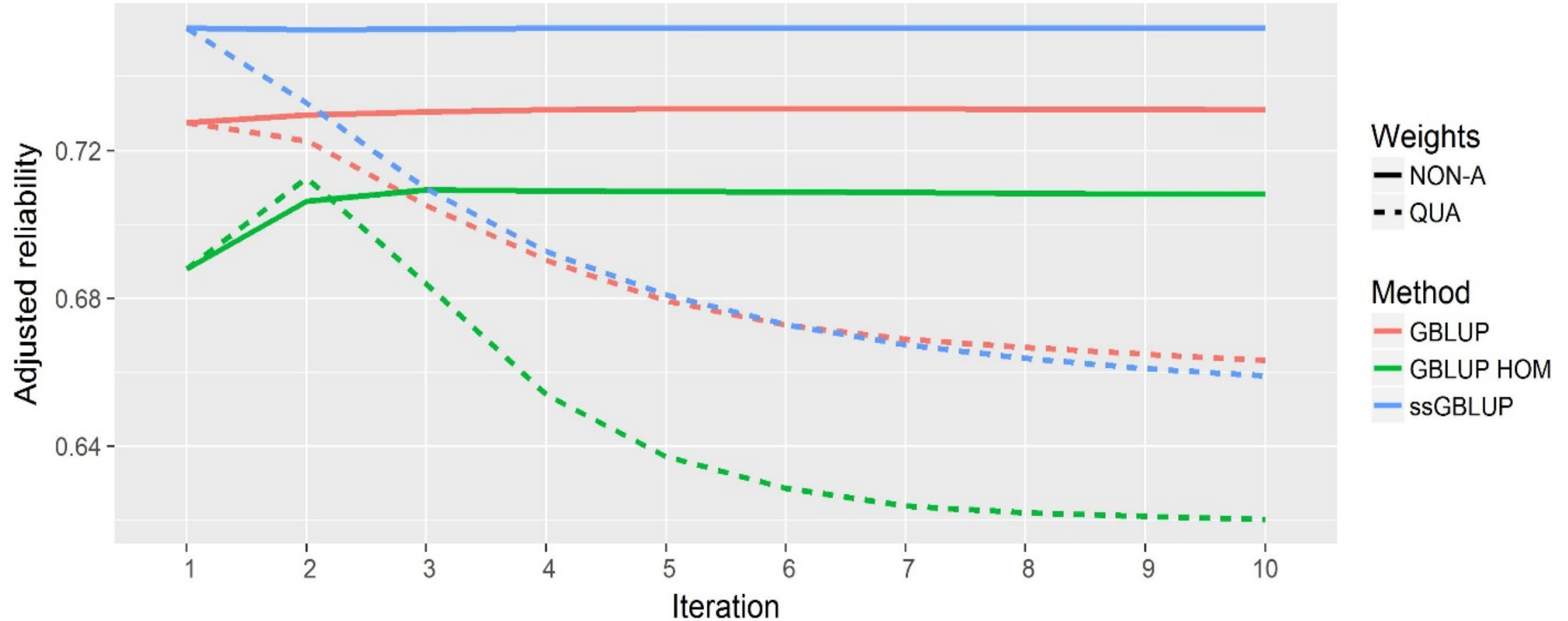
6) $\mathbf{G}_{(t+1)} = \frac{\mathbf{ZD}_{(t+1)}\mathbf{Z}'}{2 \sum p_i(1-p_i)}$

Diagonal matrix of weights

*“Iterative method
needs
convergence”*

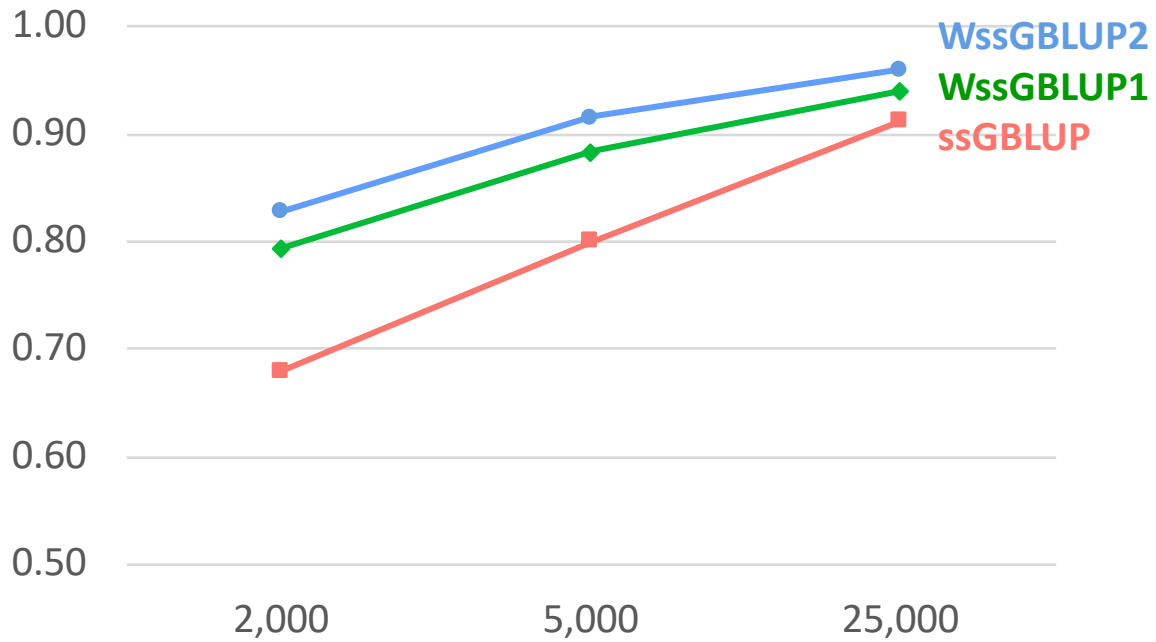


Convergence for nonlinear A and quadratic weight

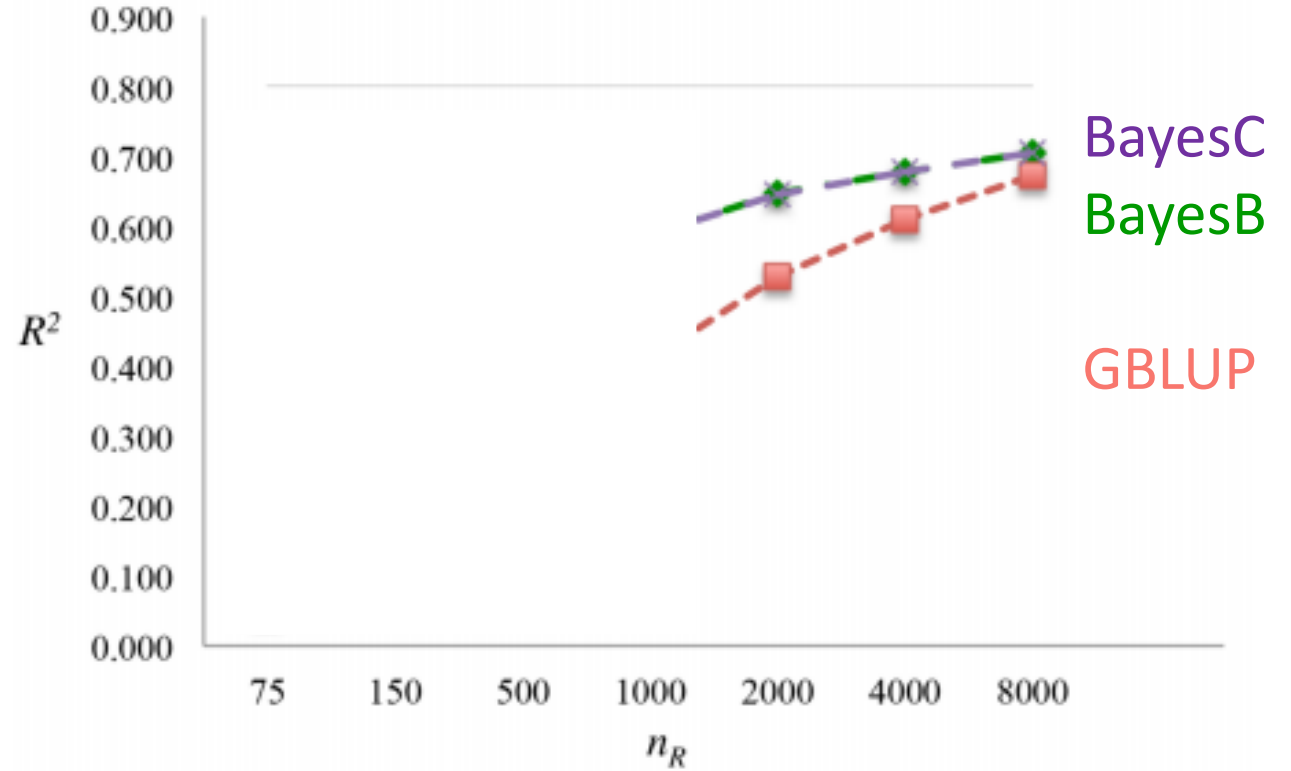


WssGBLUP for large populations

10 QTN



Lourenco et al. (2017)



Karaman et al. (2016)

How to compute SNP effect and weight in BLUP90?

- After renumf90 and preGSf90 to save clean files:
 - blupf90 to estimate GEBV
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION saveGInverse
 - OPTION saveA22Inverse
 - postGSf90 to backsolve GEBV to SNP effect
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION readGInverse
 - OPTION readA22Inverse
 - OPTION which_weight `nonlinearA`

OPTION which_weight nonlinearA

```
OPTION which_weight nonlinearA
```

This option assumes the default constant (CT) is 1.125. To change the constant value to reflect a distribution closer to normal, use a CT value closer to 1:

```
OPTION which_weight nonlinearA 1.05
```

By default, the maximum change in SNP variance is limited to 5, which is calculated as $CT^{(5-2)}$ and returns a value of 1.4238 with $CT=1.125$. If this limit is to be changed to 10, the following option can be used, where the value provided (x) is the result of the expression $CT^{(x-2)}$. As an example, if CT is 1.05 and x is 10, the value provided to the option should be 1.4775:

```
OPTION SNP_variance_limit 1.4775
```

How to run WssGBLUP in BLUPF90

- After renumf90 and preGSf90 to save clean files:
 - Blupf90 to estimate GEBV
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION saveGInverse
 - OPTION saveA22Inverse
 - OPTION weightedG `w.txt` #vector of weights
 - postGSf90 to backsolve GEBV to SNP effect
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION readGInverse
 - OPTION readA22Inverse
 - OPTION which_weight `nonlinearA`
 - OPTION weightedG `w.txt` #vector of weights
 - OPTION windows_variance 1

How to run WssGBLUP for 3 iterations in BLUPF90

```
awk 'BEGIN { for (i==1;i<45000;i++) print 1}' > w.txt # number of lines = number of SNP
```

```
for j in {1..3}
```

```
do
```

```
echo blup.par | blupf90 | tee blup.log1_$j  
cp solutions solutions1_$j  
echo post.par | postGSf90 | tee post.log1_$j  
cp snp_sol snp_sol1_$j  
cp w.txt w.txt_$j  
awk '{ if ($1==1) print $7}' snp_sol > w.txt  
mkdir plot1_$j  
cp chr.snp plot1_$j/chr.snp  
cp chr.snpvar plot1_$j/chr.snpvar  
rm chr.snp chr.snpvar snp_sol solutions
```

```
done
```

```
rm Gi A22i
```

Output from postGSf90

`snp_sol`

<http://nce.ads.uga.edu/wiki/doku.php?id=readme.pregsf90>

contains solutions of SNP and weights

- 1: trait
- 2: effect
- 3: SNP
- 4: Chromosome
- 5: Position
- 6: SNP solution
- 7: weight

if `OPTION windows_variance` is used

- 8: variance explained by n adjacents SNP.

Single-step GWAS

Genome-Wide Association Studies

Current standard for GWAS

- Run single marker regression with \mathbf{G} to compensate for relationships
 - $\mathbf{y} = \mathbf{X}\mathbf{b} + \mathbf{z}a + \mathbf{u} + \mathbf{e}$
 - \mathbf{z} : gene content {0,1,2}
 - a : marker effect

- Get p-values from $pval_i = 2 \left(1 - \Phi \left(\left| \frac{\hat{a}_i}{sd(\hat{a}_i)} \right| \right) \right)$

- Apply Bonferroni to correct for multiple testing

$$\text{Bonferroni correction} = \frac{0.05}{\text{Number of SNP}}$$

- Assumption: Genotyped individuals have phenotypes

GWAS in livestock populations

- Most animals are non-genotyped
- Animals may not have phenotypes
- Some traits are sex-limited
 - milk, fat, protein
- Single marker regression
 - Only genotyped animals with phenotypes
 - Deregressed EBV
- Need a method that fits the livestock data

Single-step GWAS

SNP
effects

GEBVs

$$\hat{\mathbf{a}} = \lambda \mathbf{Z}' \mathbf{G}^{-1} \hat{\mathbf{u}}$$

VanRaden 2008
Stranden and Garrick 2009
Wang et al. 2012

a) Quadratic SNP weights (Falconer & Mackay, 1996)

$$d_i = \hat{a}_i^2 2p_i(1 - p_i)$$

b) Nonlinear A SNP weights (VanRaden, 2008)

$$d_i = 1.125 \frac{|\hat{a}_i|}{sd(\hat{\mathbf{a}})} - 2$$

How to run ssGWAS in BLUPF90

- After renumf90 and preGSf90 to save clean files:
 - **Blupf90 to estimate GEBV** Do not run iterations for ssGWAS!
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION saveGInverse
 - OPTION saveA22Inverse
 - OPTION weightedG `w.txt` #vector of weights
 - **postGSf90 to backsolve GEBV to SNP effect**
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION readGInverse
 - OPTION readA22Inverse
 - ##OPTION which_weight `nonlinearA`
 - OPTION weightedG `w.txt` #vector of weights
 - OPTION windows_variance `1`

postGSf90 options

```
OPTION SNP_moving_average n
```

Solutions for SNP effects will be by moving average of n adjacent SNPs.

```
OPTION windows_variance n
```

Calculates the variance explained by n adjacent SNPs.

When this option is used, the sum of variance explained by n adjacent SNPs (column 8 of `snp_sol` or column 3 of `chrnpvar`) is not 100%. This is because moving variance is used. If windows size is 20, the proportion of variance assigned to SNP 1 is calculated from SNP 1 to 20, for SNP 2 it goes from 2 to 21, for SNP 3 it goes from 3 to 22, and so forth. A file called `windows_variance` has variance that sums to 100% in column 9.

```
OPTION windows_variance_mbp n
```

Calculates the variance explained by n Mb window of adjacent SNPs.

```
OPTION which_weight x
```

Generates a weight variable w to be used in the creation of a weighted genomic relationship matrix $G=ZDZ'$

- 1: $w = y^2 * (2(p(1-p)))$
- 2: $w = y^2$
- 3: experimental with the degree of brief
- 4: $w = C^{**}(\text{abs}(y)/\text{sqrt}(\text{var}(y's)))-2$ from VanRaden et al. (2009)
- nonlinearA: same as 4

postGSf90 options

```
OPTION Manhattan_plot
```

Plot using GNUPLOT the Manhattan plot (SNP effects) for each trait and correlated effect.

```
OPTION Manhattan_plot_R
```

Plot using R the Manhattan plot (SNP effects) for each trait and correlated effect.
`pdf` images are created: *manplot_St1e2.pdf*, but other formats can be specified.
Note: *t1e2* corresponds to trait 1, effect 2.

```
OPTION Manhattan_plot_R_format <format>
```

Control the format type to create images in R
`format` values accepted:

- pdf (default)
- png
- tif

```
OPTION plotsnp <n>
```

Control the values of SNP effects to use in Manhattan plots

- 1: plot regular SNP effects: `abs(val)`
- 2: plot standardized SNP effects: `abs(val/sd)` (default)

Output from postGSf90

<http://nce.ads.uga.edu/wiki/doku.php?id=readme.pregsf90>

chr_{snp}

contains data to create plot by GNUPLOT

- 1: trait
- 2: effect
- 3: values of SNP effects to use in Manhattan plots
- 4: SNP
- 5: Chromosome
- 6: Position

chr_{snpvar}

contains data to create plot by GNUPLOT

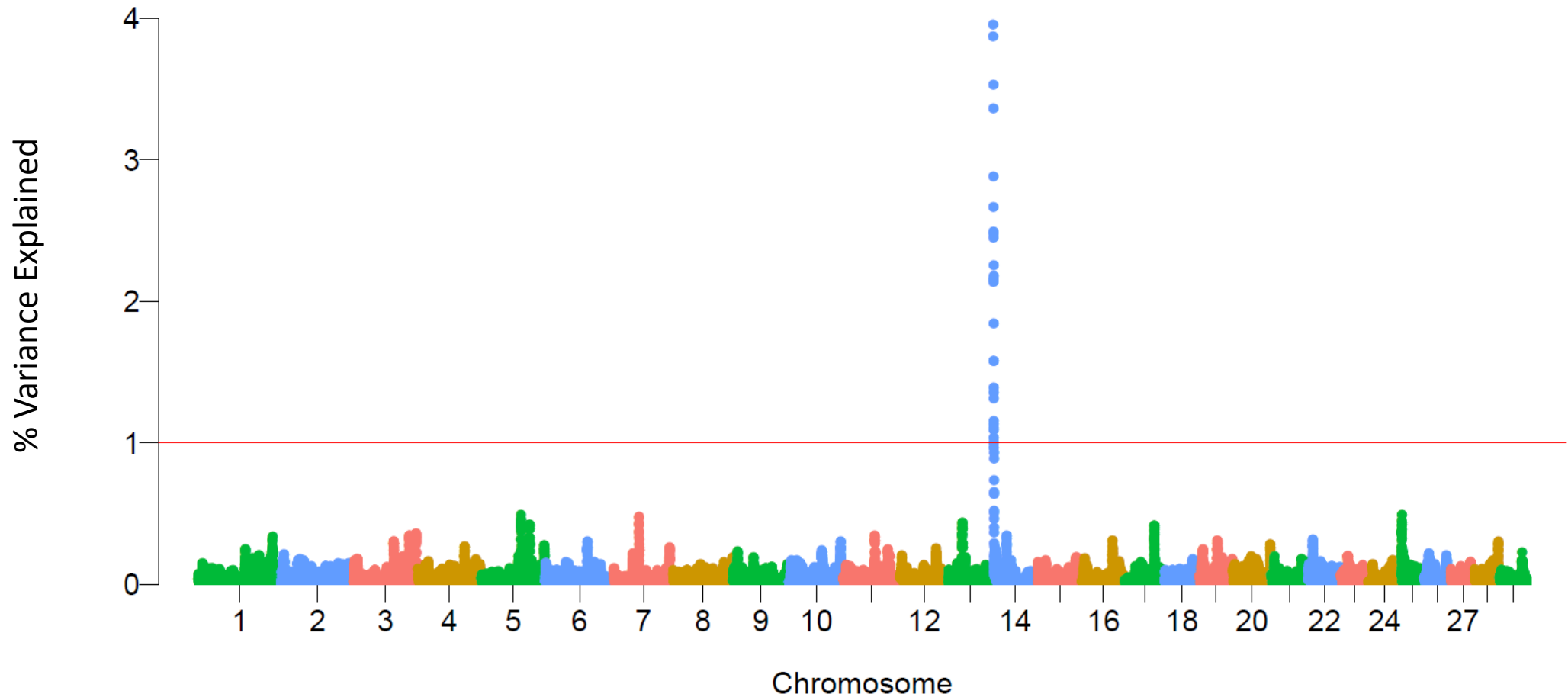
- 1: trait
- 2: effect
- 3: variance explained by n adjacent SNPs
- 4: SNP
- 5: Chromosome
- 6: Position

Single-step GWAS

Fat – US Holsteins

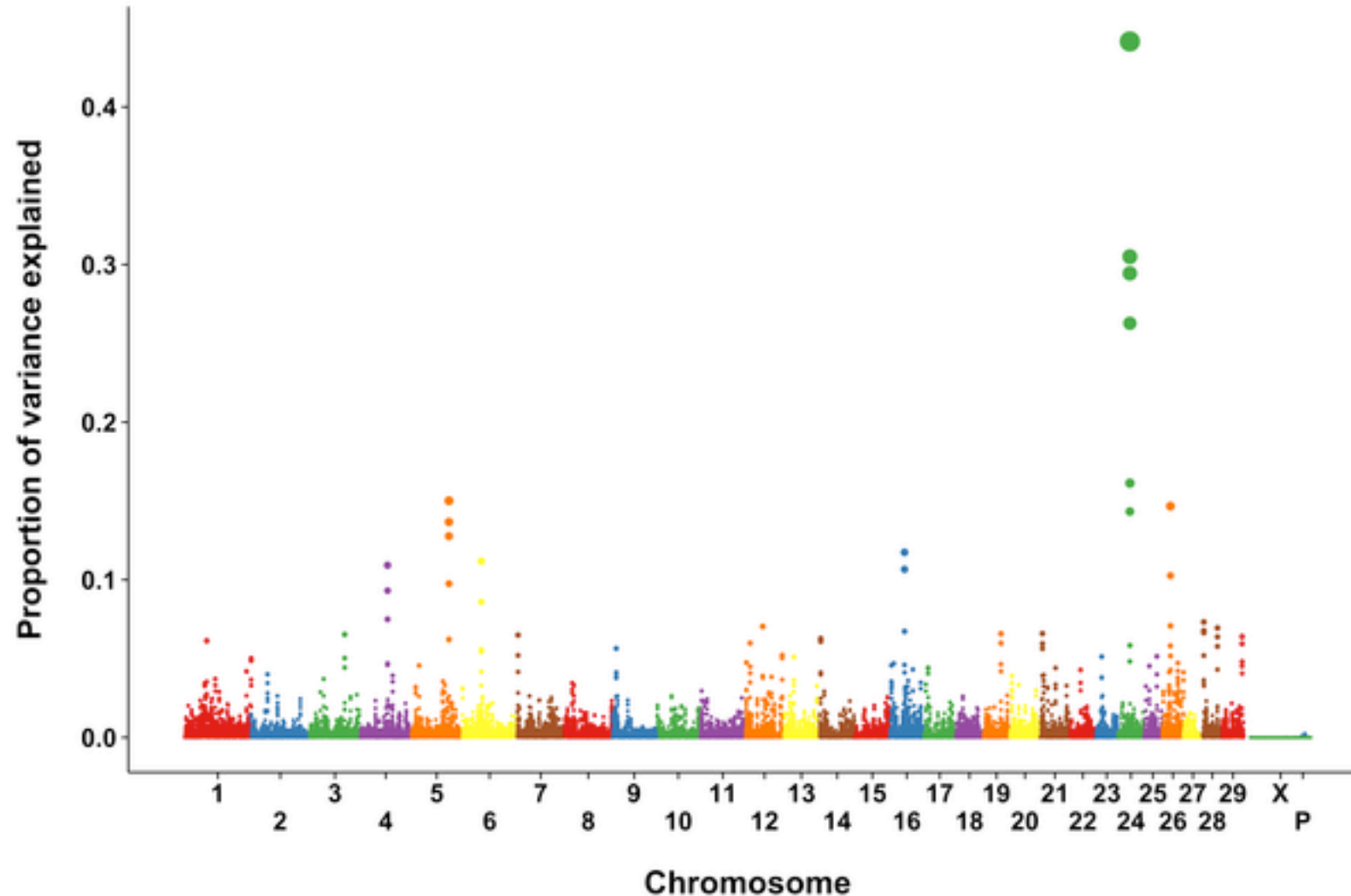
No P-value!!!

Manhattan plot of Variances



Single-step GWAS

Figure 2. Proportion of SNP variance explained by 5-SNP moving windows for rectal temperature from a **single-step GBLUP** analysis



No P-value!!!

Can we have p-values in ssGWAS?

Gualdrón Duarte et al. *BMC Bioinformatics* 2014, 15:246
<http://www.biomedcentral.com/1471-2105/15/246>



METHODOLOGY ARTICLE

Open Access

Rapid screening for phenotype-genotype associations by linear transformations of genomic evaluations

Jose L Gualdrón Duarte¹, Rodolfo JC Cantet¹, Ronald O Bates², Catherine W Ernst², Nancy E Raney² and Juan P Steibel^{2,3*}

Genome-Wide Association Analyses Based on Broadly Different Specifications for Prior Distributions, Genomic Windows, and Estimation Methods

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ANIMAL GENETICS Immunogenetics, Molecular Genetics and Functional Genomics 

doi: 10.1111/age.12378

Meta-analysis of genome-wide association from genomic prediction models

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J. Dairy Sci. 101:3140–3154
<https://doi.org/10.3168/jds.2017-13364>
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Genome-wide association analyses based on a multiple-trait approach for modeling feed efficiency

Y. Lu,^{*} M. J. VanDehaar,^{*} D. M. Spurlock,[†] K. A. Weigel,[‡] L. E. Armentano,[‡] E. E. Connor,[§] M. Coffey,[#] R. F. Veerkamp,^{||} Y. de Haas,^{||} C. R. Staples,[¶] Z. Wang,^{**} M. D. Hanigan,^{††} and R. J. Tempelman^{*1}

P-values in ssGWAS

1) Factorize and Invert LHS of ssGBLUP with YAMS (Masuda et al., 2014)

2) Solve the MME for $\begin{bmatrix} \hat{\beta} \\ \hat{u} \end{bmatrix}$ using the sparse Cholesky factor

3) Extract from LHS⁻¹ coefficients for genotyped animals ($\mathbf{C}^{u_2 u_2}$)

4) Obtain individual prediction error variance of SNP effects:

$$Var(\hat{a}_i) = \frac{1}{2\sum p_i q_i} \mathbf{z}'_i \mathbf{G}^{-1} (\mathbf{G}\sigma_u^2 - \mathbf{C}^{u_2 u_2}) \mathbf{G}^{-1} \mathbf{z}_i \frac{1}{2\sum p_i q_i}$$

(Gualdron-Duarte et al., 2014)

5) Backsolve GEBV to SNP effects (\hat{a}): $\hat{a} = \frac{1}{2\sum p_i q_i} \mathbf{Z}' \mathbf{G}^{-1} \hat{u}$

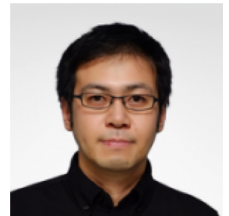
6) $p\text{-value}_i = 2 \left(1 - \Phi \left(\left| \frac{\hat{a}_i}{sd(\hat{a}_i)} \right| \right) \right)$

Φ is the cumulative standard normal function

blupf90



Ignacio
Aguilar



Yutaka
Masuda

postGSf90



Andres
Legarra

OPTION in blupf90 and postGSf90

- Single option for both programs

OPTION snp_p_value

- Output

trait	effect	$-\log_{10}(\text{p-value})$	SNP	CHR	POS
1	5	0.6467097526	1	1	120183
1	5	0.3510786763	2	1	135098
1	5	0.3606678137	3	1	158820
1	5	0.2585950992	4	1	183040
1	5	0.6969161959	5	1	208728
1	5	1.7646253513	6	1	267940
1	5	1.0802326921	7	1	278952
1	5	0.6819748588	8	1	290690
1	5	1.0131137254	9	1	309487
1	5	0.0038533074	10	1	393248

Aguilar et al. *Genet Sel Evol* (2019) 51:28
<https://doi.org/10.1186/s12711-019-0469-3>



SHORT COMMUNICATION

Open Access

Frequentist p-values for large-scale-single step genome-wide association, with an application to birth weight in American Angus cattle

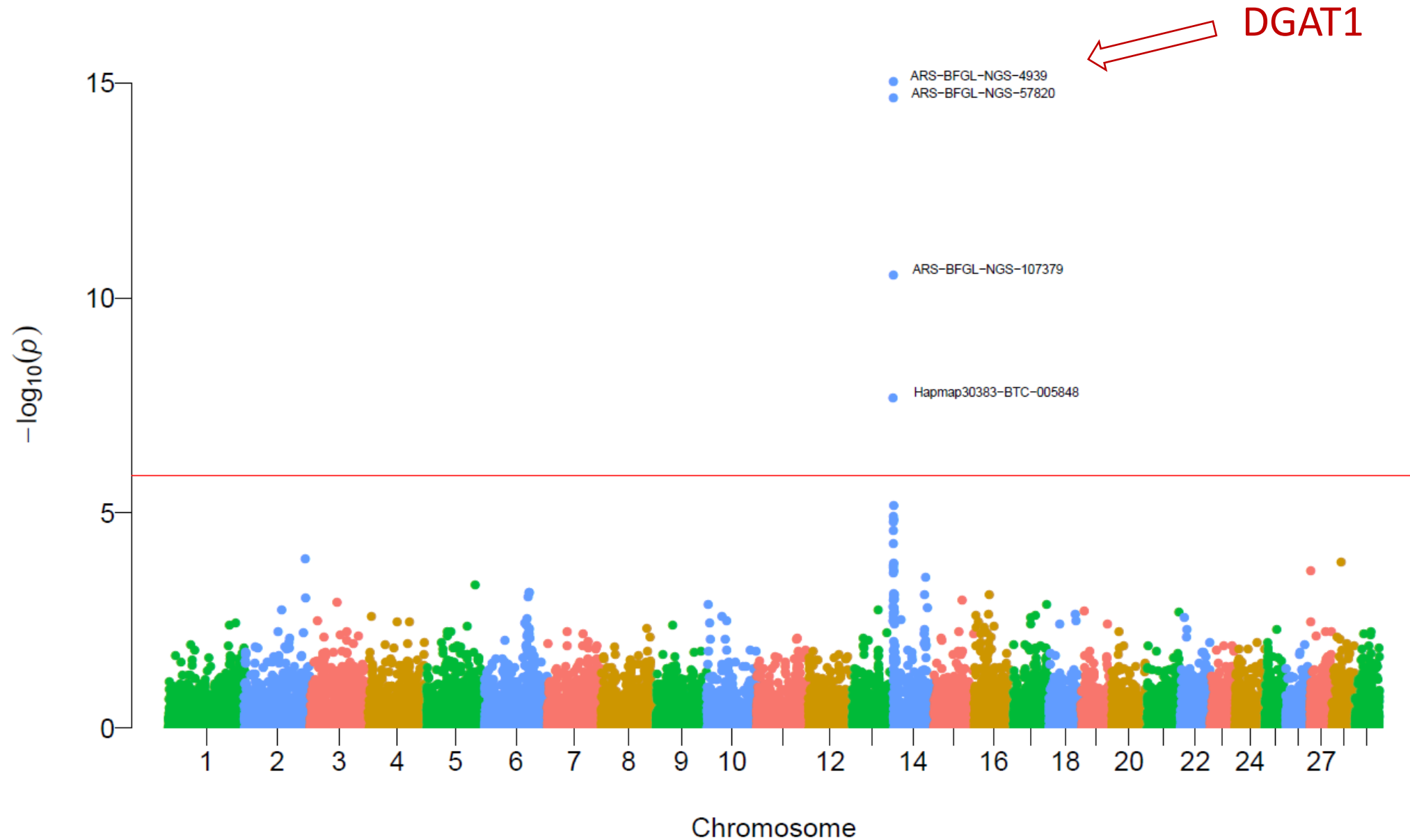


Ignacio Aguilar¹, Andres Legarra^{2*}, Fernando Cardoso^{3,4}, Yutaka Masuda⁵, Daniela Lourenco⁵ and Ignacy Misztal⁵

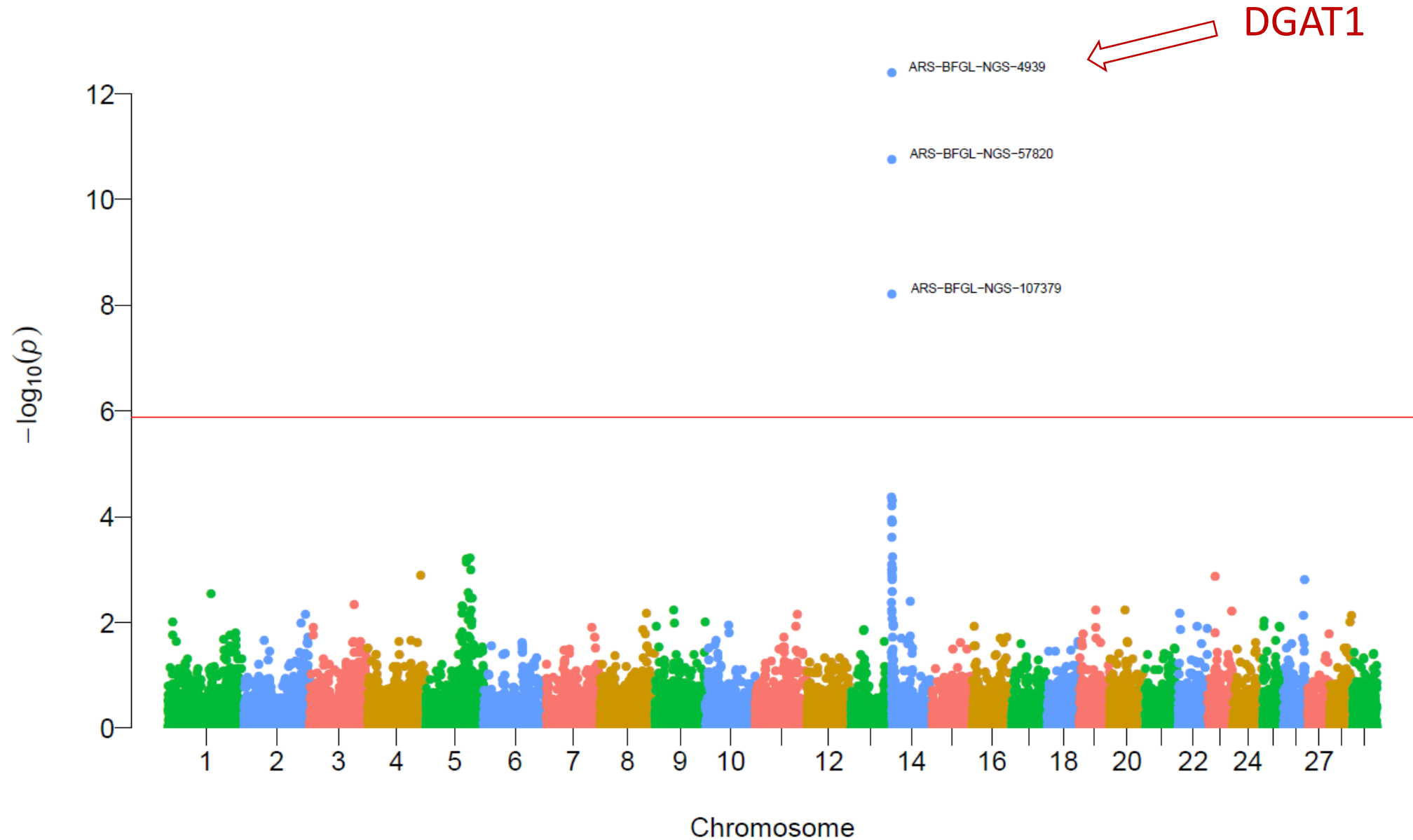
P-values in ssGWAS for US Holsteins

- US HOL 2009 data: milk, fat, protein
- Single-trait models
 - 10k genotyped bulls
 - 752k records for 100k daughters
 - 303k animals in ped

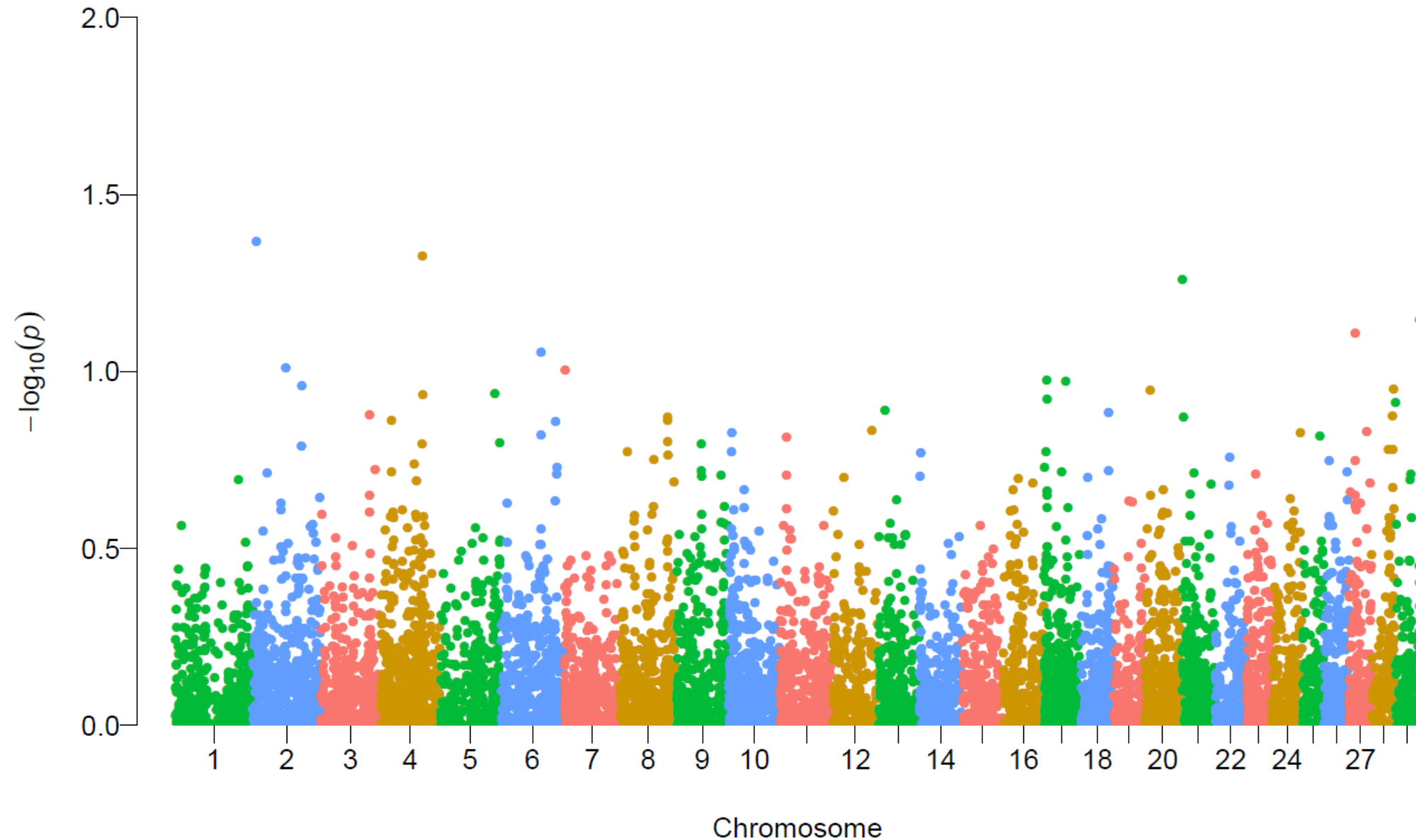
P-values in ssGWAS - Milk



P-values in ssGWAS - Fat



P-values in ssGWAS - Protein



How to run ssGWAS with p-values in BLUPF90

- Should not use iterations!
- After renumf90 and preGSf90 to save clean files:
 - **Blupf90 to estimate GEBV**
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION saveGInverse
 - OPTION saveA22Inverse
 - OPTION snp_p_value
 - **postGSf90 to backsolve GEBV to SNP effect**
 - OPTION SNP_file `snp.dat`
 - OPTION chrinfo `mrkmap.txt`
 - OPTION readGInverse
 - OPTION readA22Inverse
 - ##OPTION which_weight `nonlinearA`
 - OPTION windows_variance `1`
 - OPTION snp_p_value

Output from postGSf90

```
chrnp_pval
```

contains solutions of SNP and weights

- 1: trait
- 2: effect
- 3: $-\log_{10}(\text{p-value})$
- 4: SNP
- 5: Chromosome
- 6: Position in bp

BLUPF90 Family of Programs

Now with support for genomic selection


Ignacy Misztal and collaborators, University of Georgia

BLUPF90 family of programs is a collection of software in Fortran 90/95 for mixed model computations in animal breeding. The goal of the software is to be as simple as with a matrix package and as efficient as in a programming language. For general description, see a [paper](#) from the CCB'99 workshop or see a [paper](#) on BGF90 at 7th WCGALP.

For variance component estimation, the family offers choices for simple and complicated models; see paper ["Reliable computing in estimation of variance components"](#). From 2009 the programs are successively modified for genomic selection using a [single-step](#) approach (or ssGBLUP) by Ignacio Aguilar and Shogo Tsuruta.

For support, join [blupf90](#) group at yahoo.com.

Troubleshooting

 If the software crashes with segmentation fault, please change settings in your operating system. See [FAQ:Segmentation fault](#) for details. Also, The [FAQ pages](#) provide useful suggestions and solutions.

Headline

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