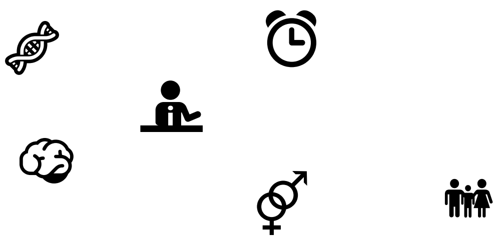
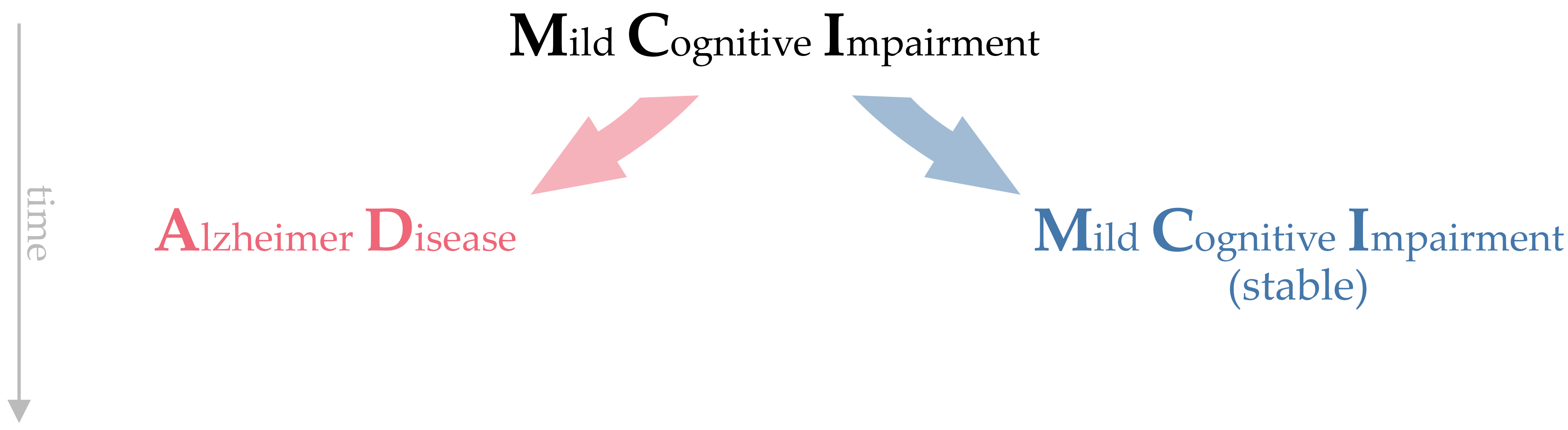
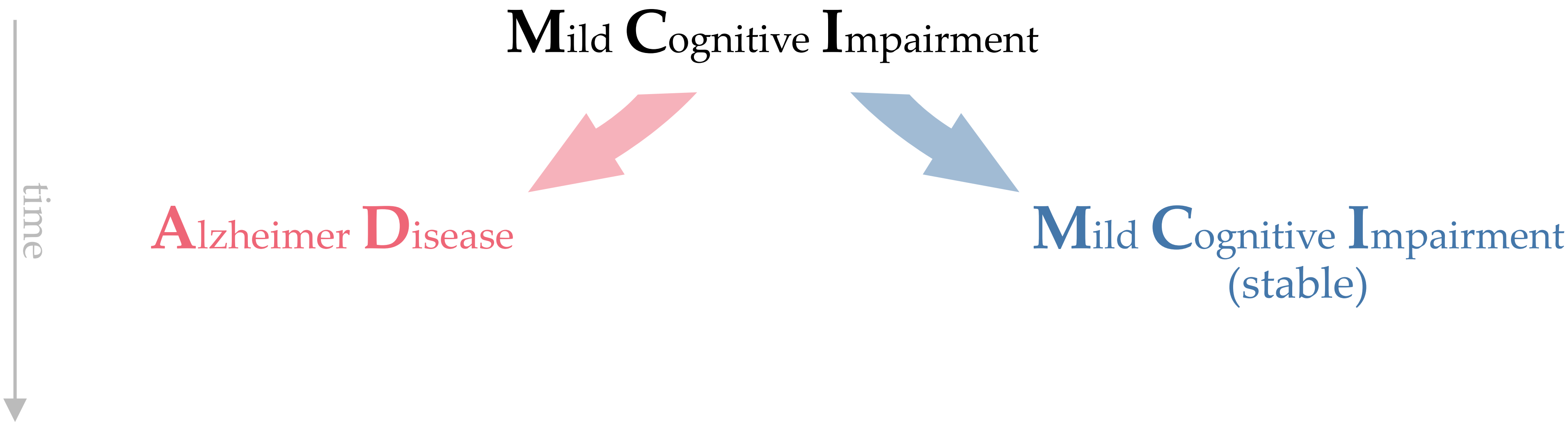
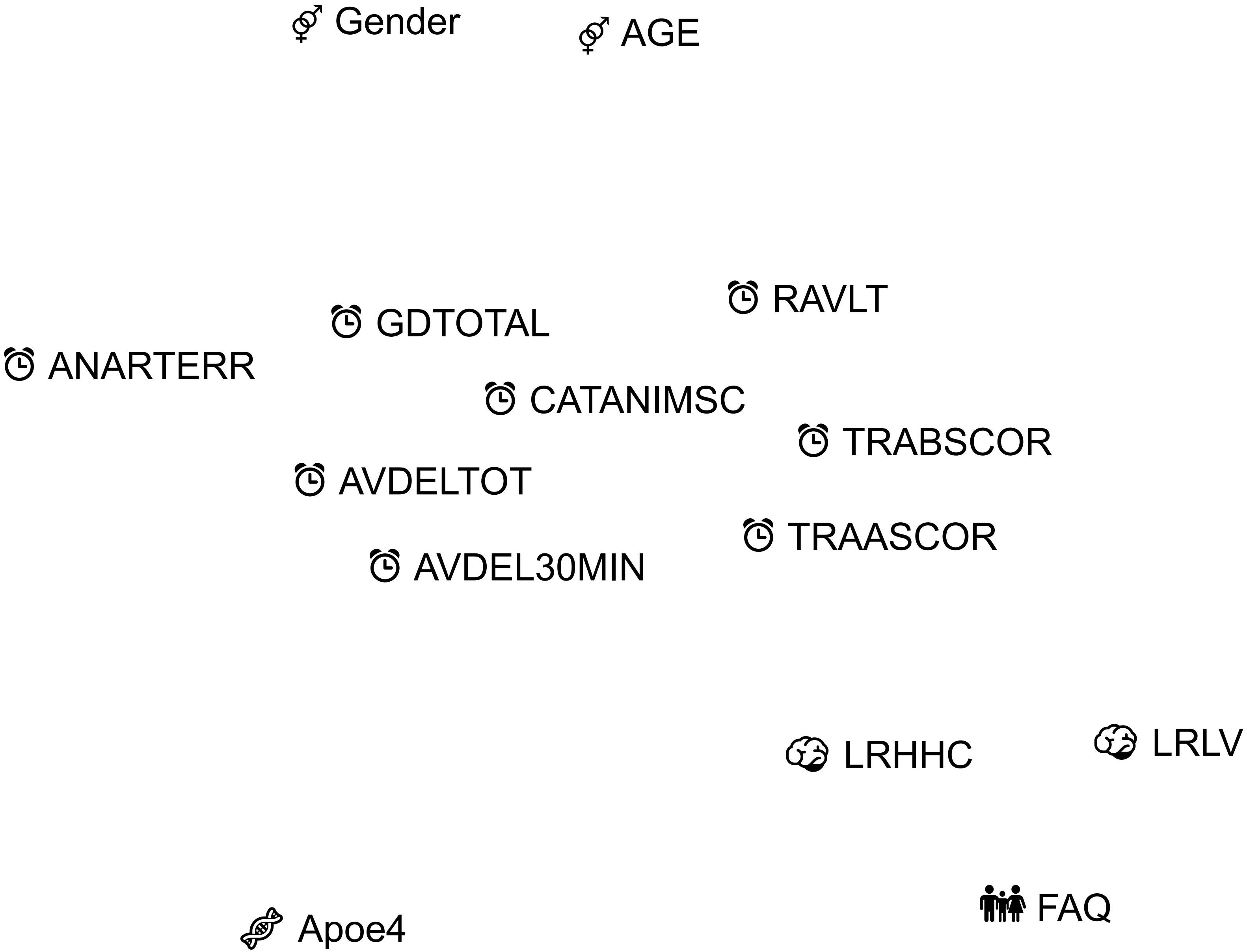


Mild Cognitive Impairment


Mild Cognitive Impairment
time
Alzheimer Disease
Mild Cognitive Impairment
(stable)


Mild Cognitive Impairment
time
Alzheimer Disease
Mild Cognitive Impairment
(stable)


Gender
AGE
RAVLT
GDTOTAL
ANARTERR
CATANIMSC
TRABSCOR
AVDELTOT
TRAASCOR
AVDEL30MIN
LRHHC
LRLV
FAQ
Apoe4

Gender

AGE

RAVLT

GDTOTAL

ANARTERR

CATANIMSC

TRABSCOR

AVDELTOT

TRAASCOR

AVDEL30MIN

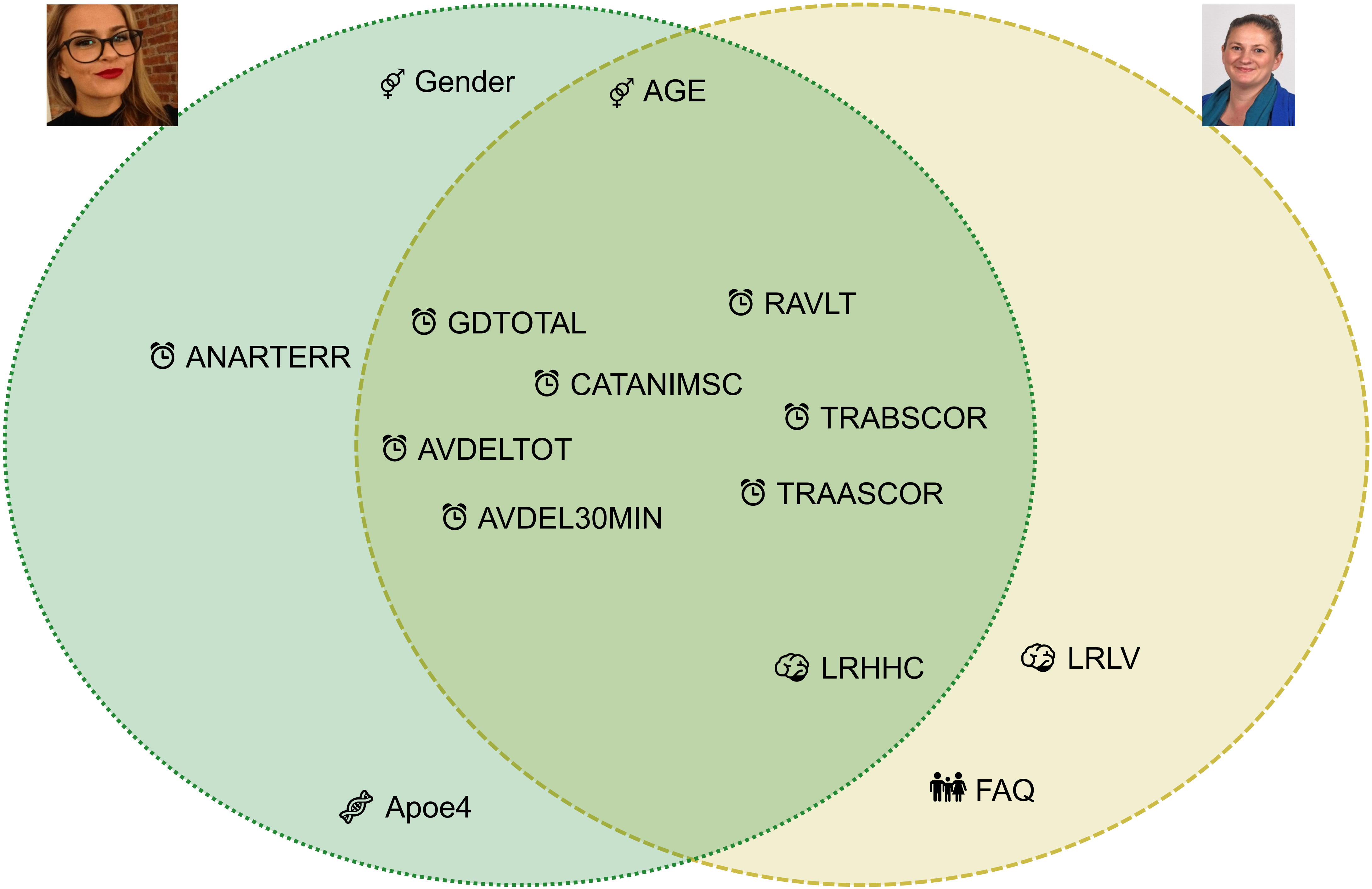
LRHHC

LRLV

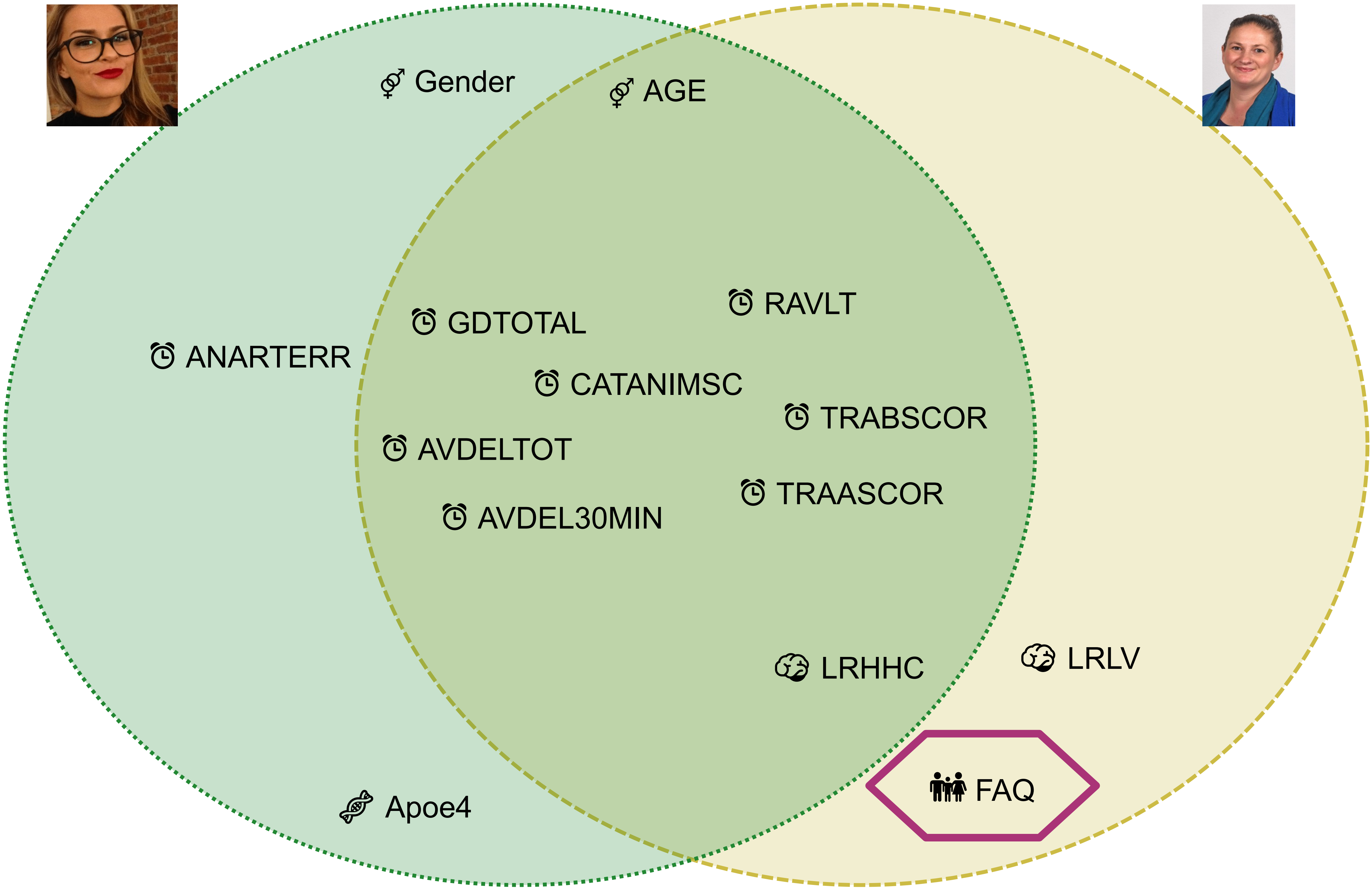
FAQ

Apoe4

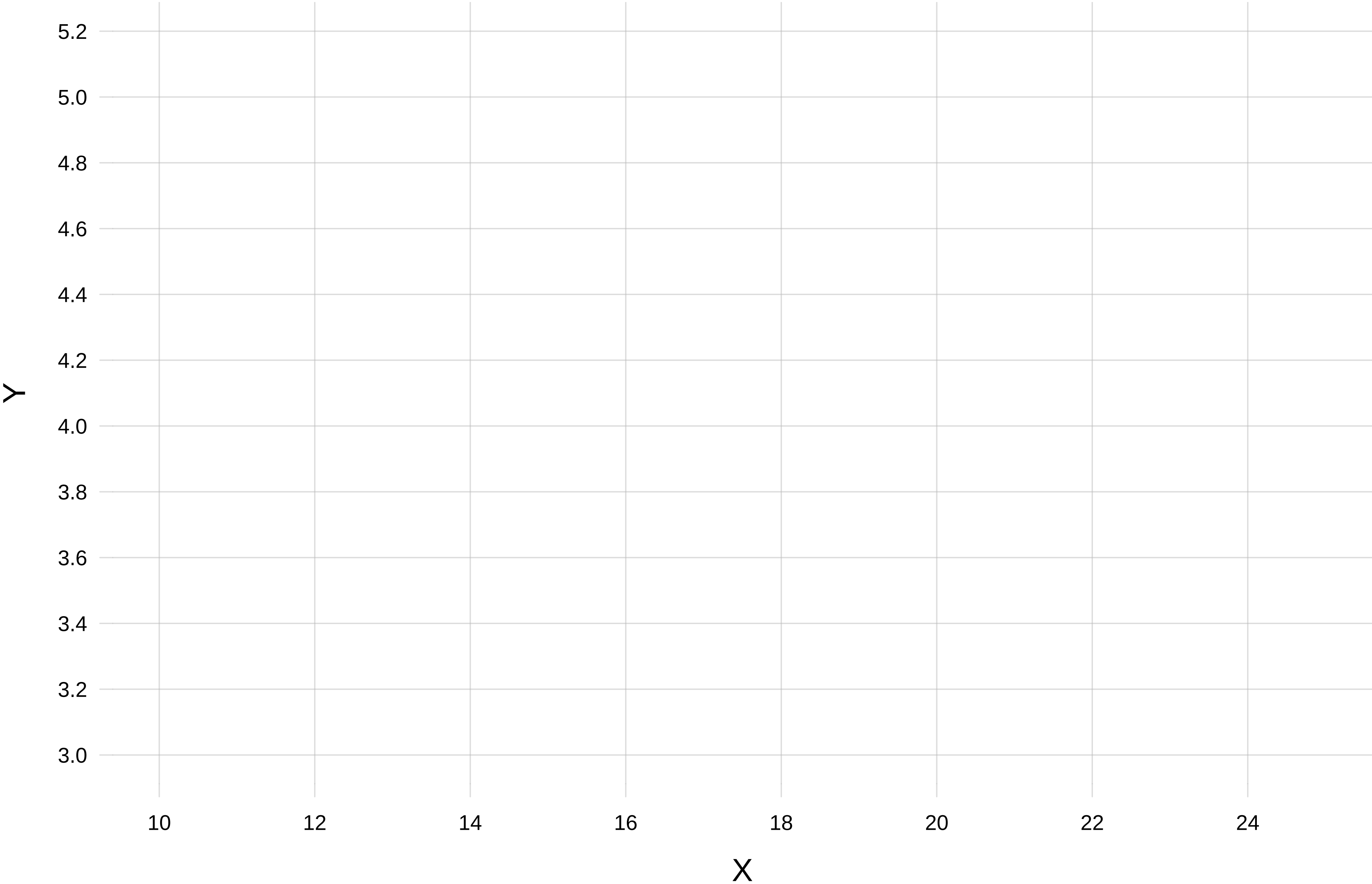
How ‘good’ are these features at prognosing the later onset of Alzheimer?

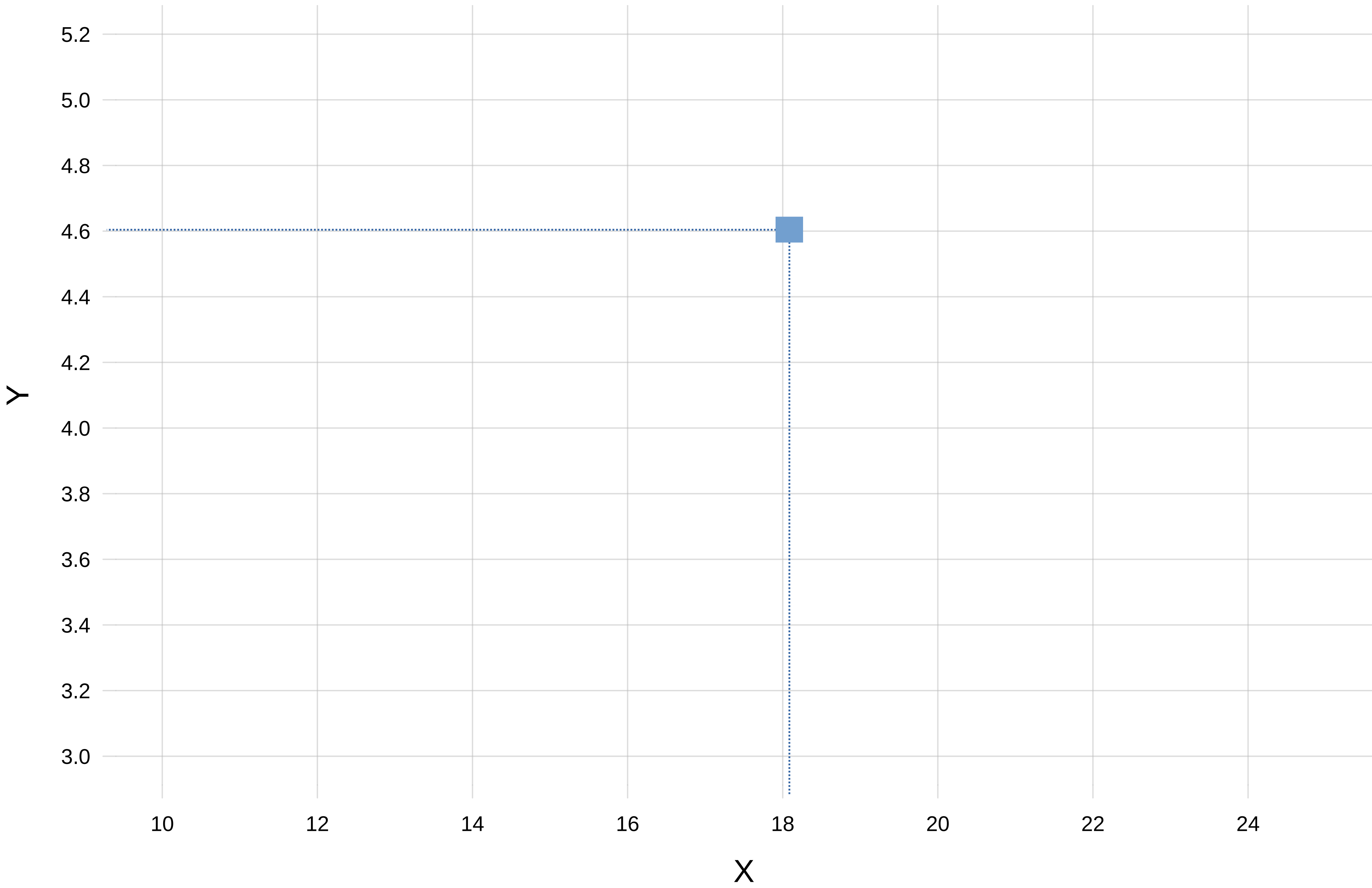


How 'good' are these features at prognosing the later onset of Alzheimer?

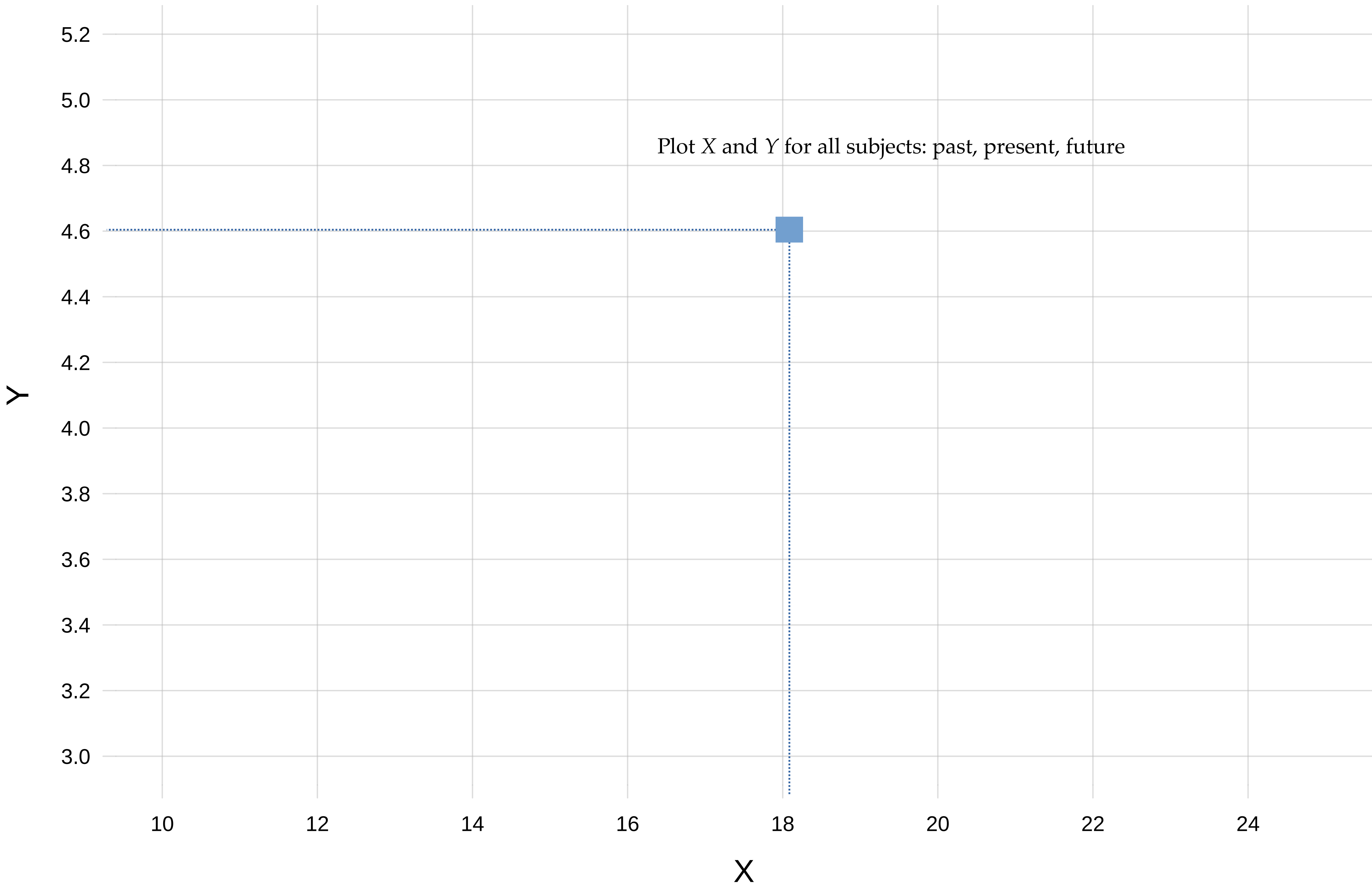


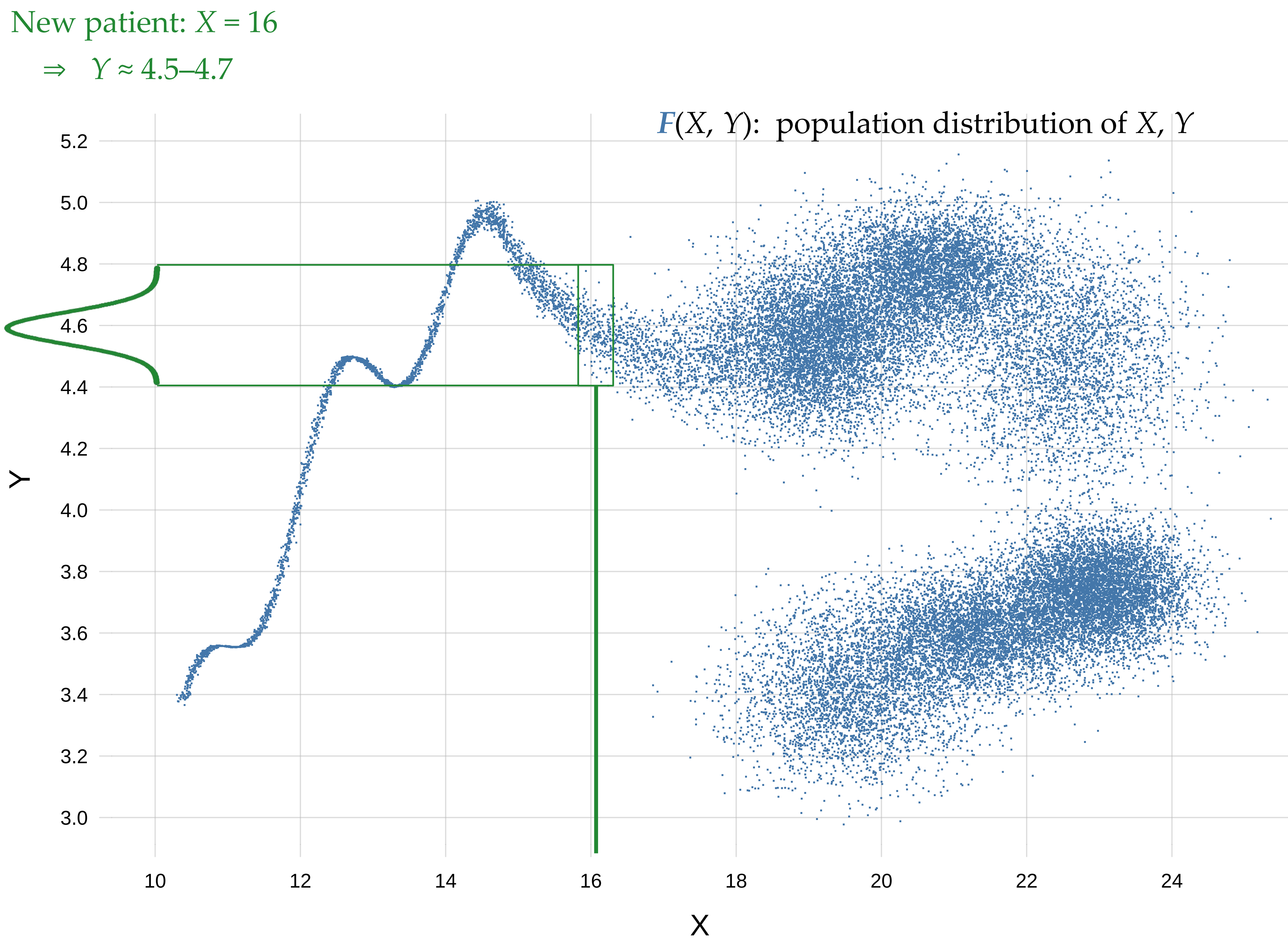
How 'good' are these features at prognosing the later onset of Alzheimer?


5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X

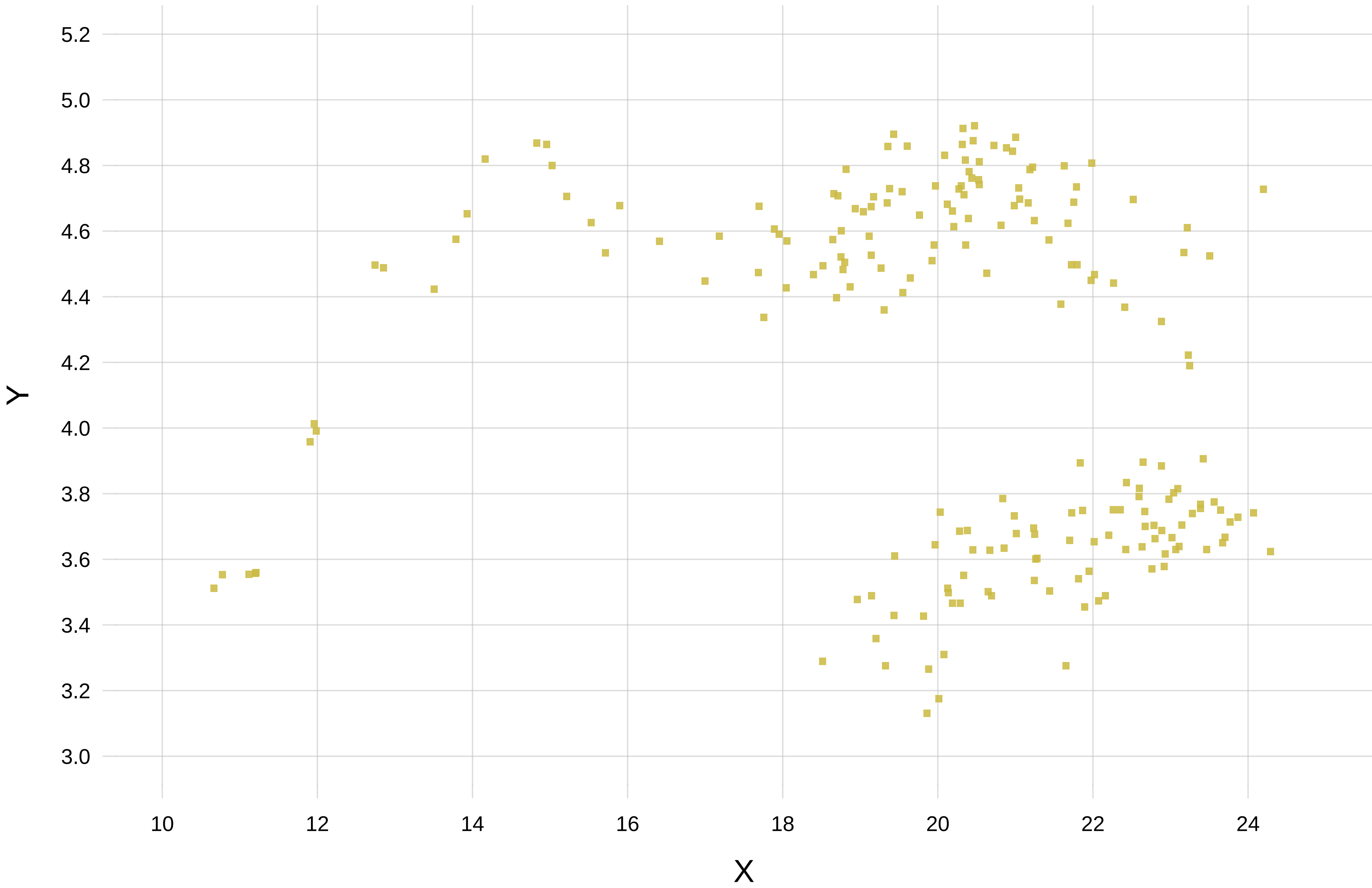


5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X


Plot X and Y for all subjects: past, present, future
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X



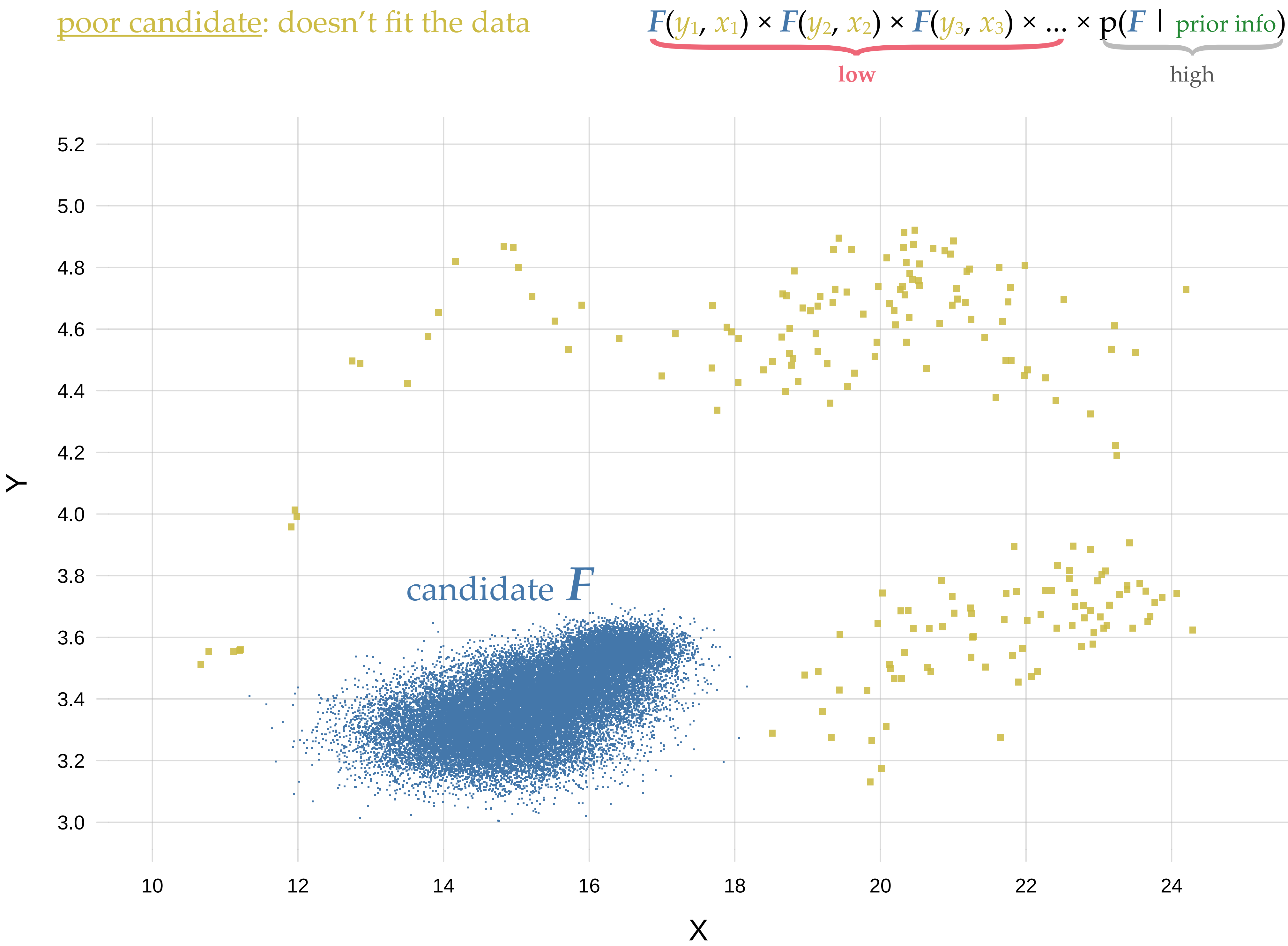
New patient: $X = 16$
$\Rightarrow$ $Y \approx 4.5–4.7$
$F(X, Y)$: population distribution of X, Y
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X


5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X

$$P(y \mid x) = \int F(y \mid x)\ p(F \mid \text{data})\ \mathrm{d}F$$

probability = average over all possible population distributions

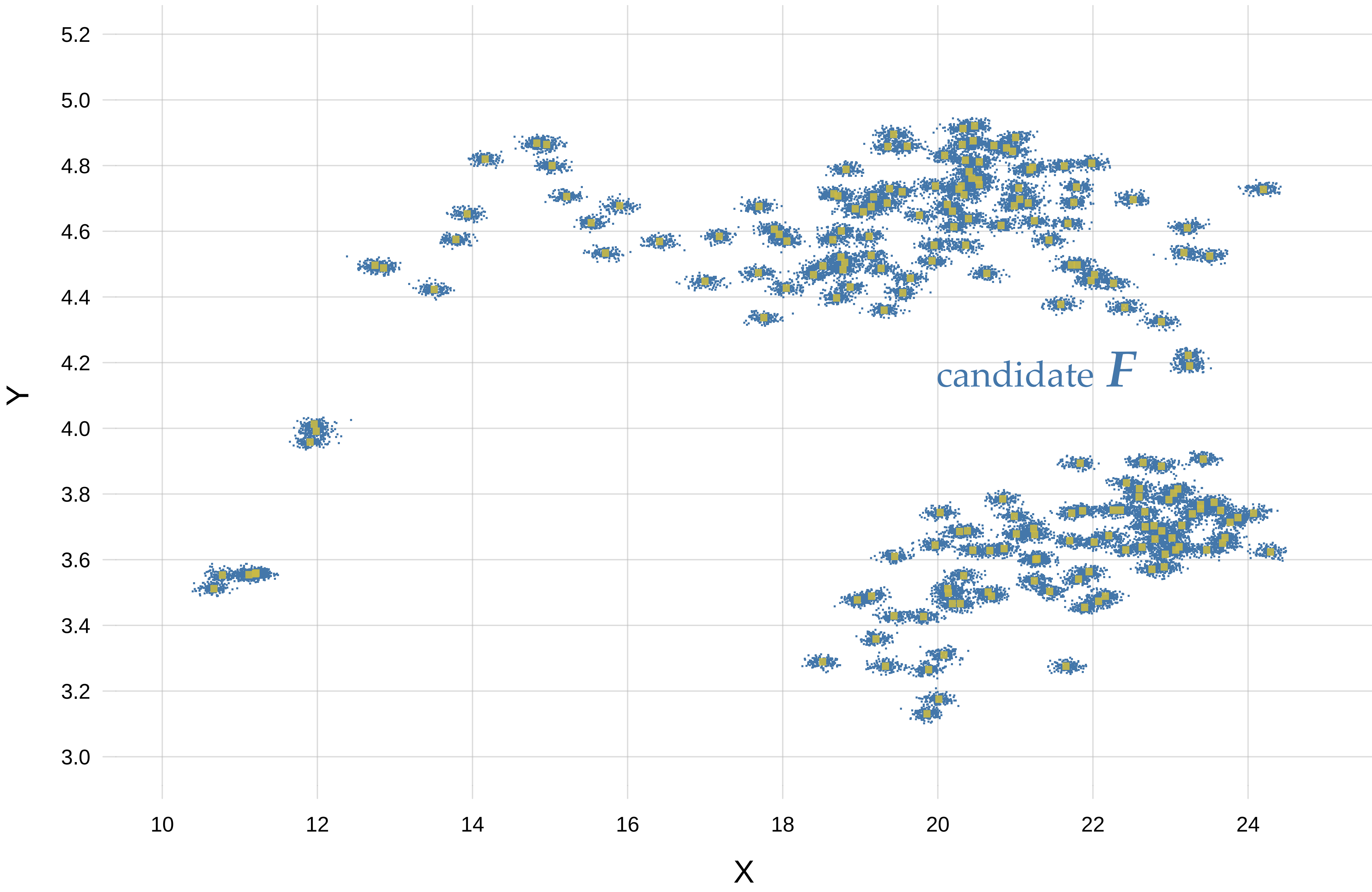
$$p(F \mid \text{data}) \propto \underbrace{F(y_1, x_1) \times F(y_2, x_2) \times F(y_3, x_3) \times \ldots}_{\text{how well the candidate distribution fits the data}} \times \underbrace{p(F \mid \text{prior info})}_{\text{extra-data knowledge}}$$



poor candidate: doesn't fit the data
$\underbrace{F(y_1, x_1) \times F(y_2, x_2) \times F(y_3, x_3) \times \dots}_{\text{low}} \times \underbrace{p(F \mid \text{prior info})}_{\text{high}}$
candidate F
Y
X
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
10
12
14
16
18
20
22
24

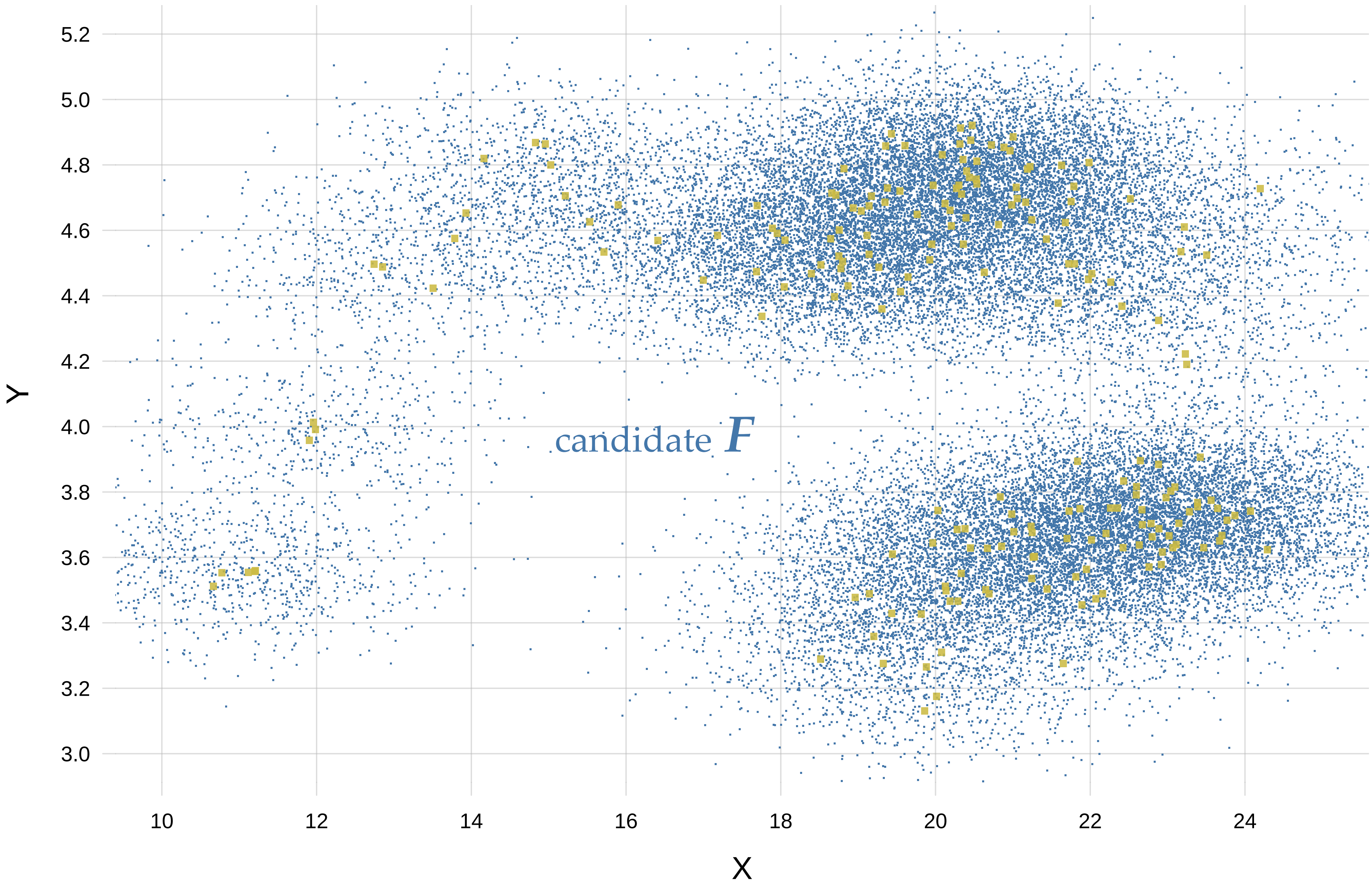
poor candidate: biologically implausible

$$\underbrace{F(y_1, x_1) \times F(y_2, x_2) \times F(y_3, x_3) \times \ldots}_{\text{high}} \times \underbrace{p(F \mid \text{prior info})}_{\text{low}}$$



reasonable candidate

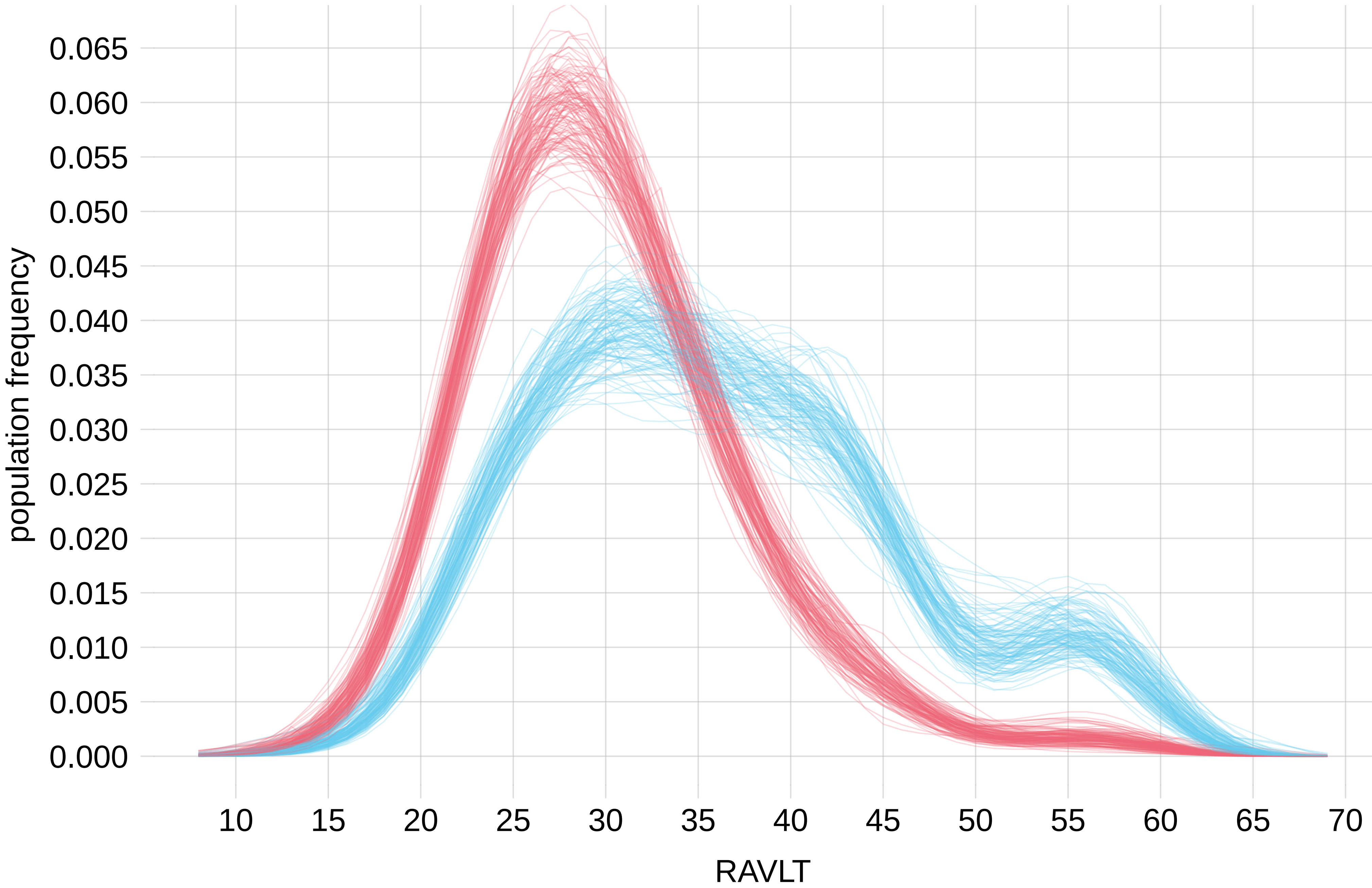
$$\underbrace{F(y_1, x_1) \times F(y_2, x_2) \times F(y_3, x_3) \times \ldots}_{\text{high}} \times \, p(\underbrace{F \mid \text{prior info}}_{\text{high}})$$



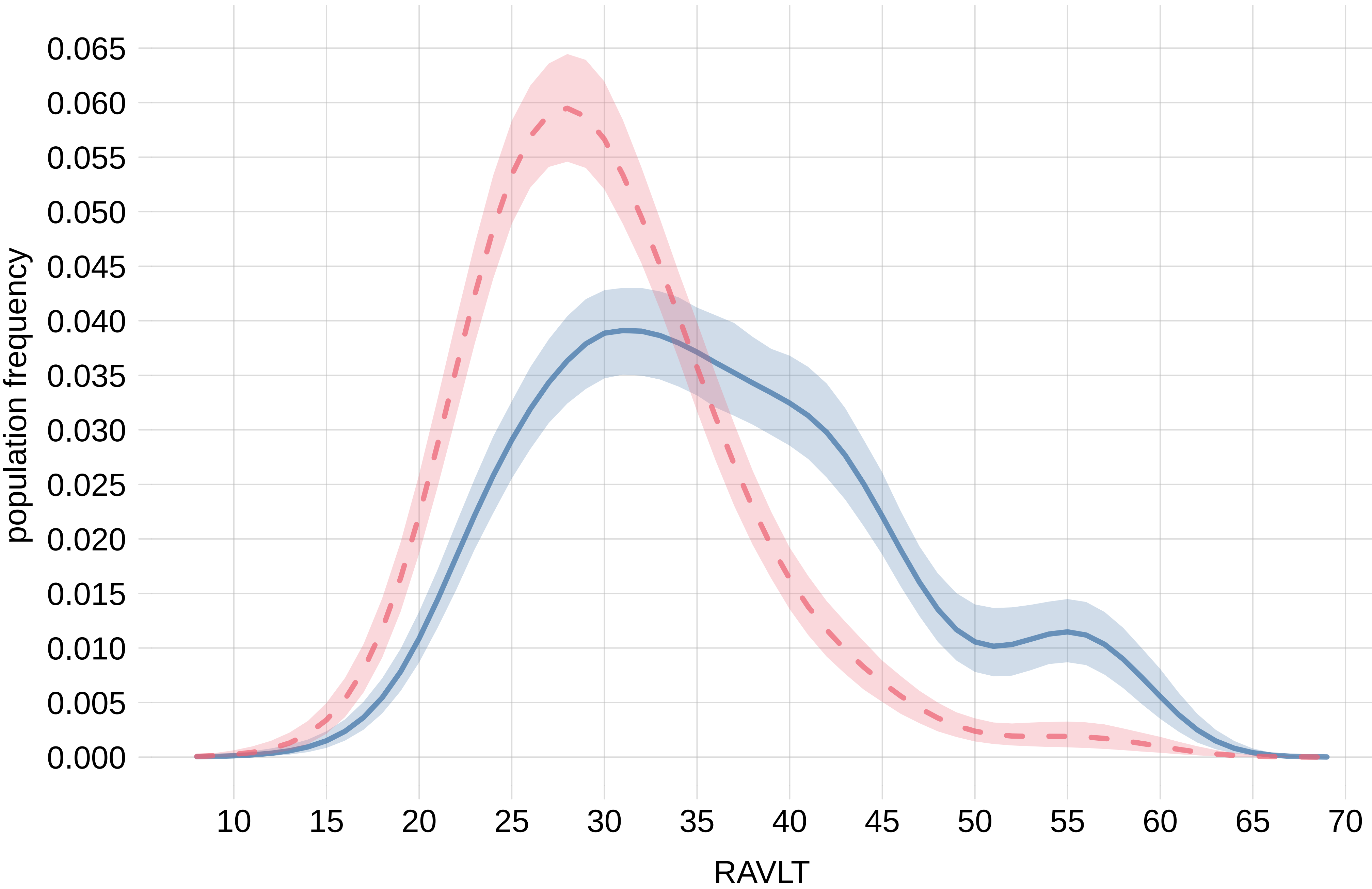
~~*intuition* $\longrightarrow$ *mathematics*~~

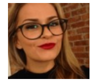
first principles $\longrightarrow$ *mathematics* $\longrightarrow$ *intuition*

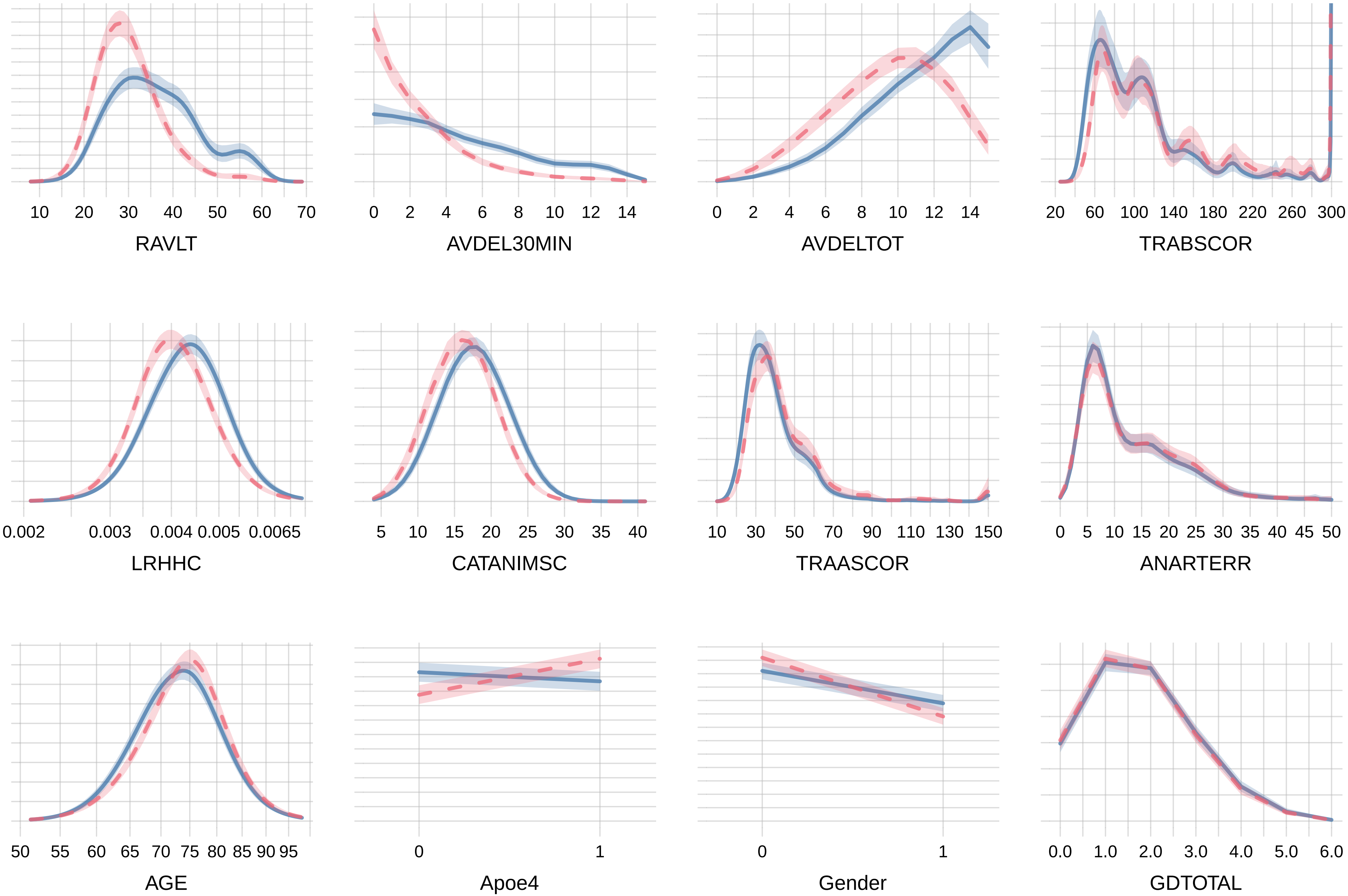
(‘Bayesian’)



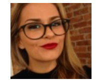
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
population frequency
10
15
20
25
30
35
40
45
50
55
60
65
70
RAVLT

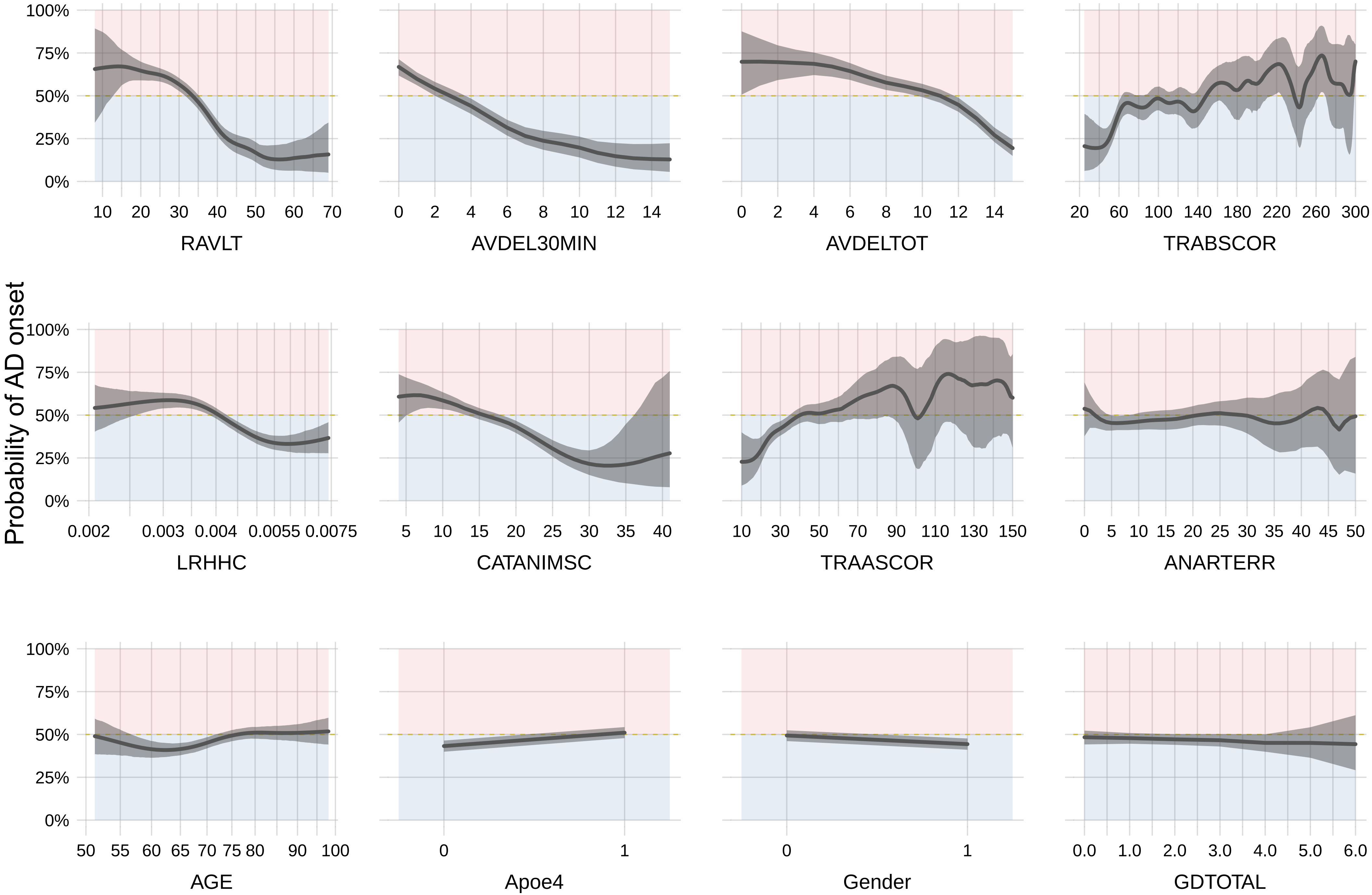

0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
population frequency
10
15
20
25
30
35
40
45
50
55
60
65
70
RAVLT

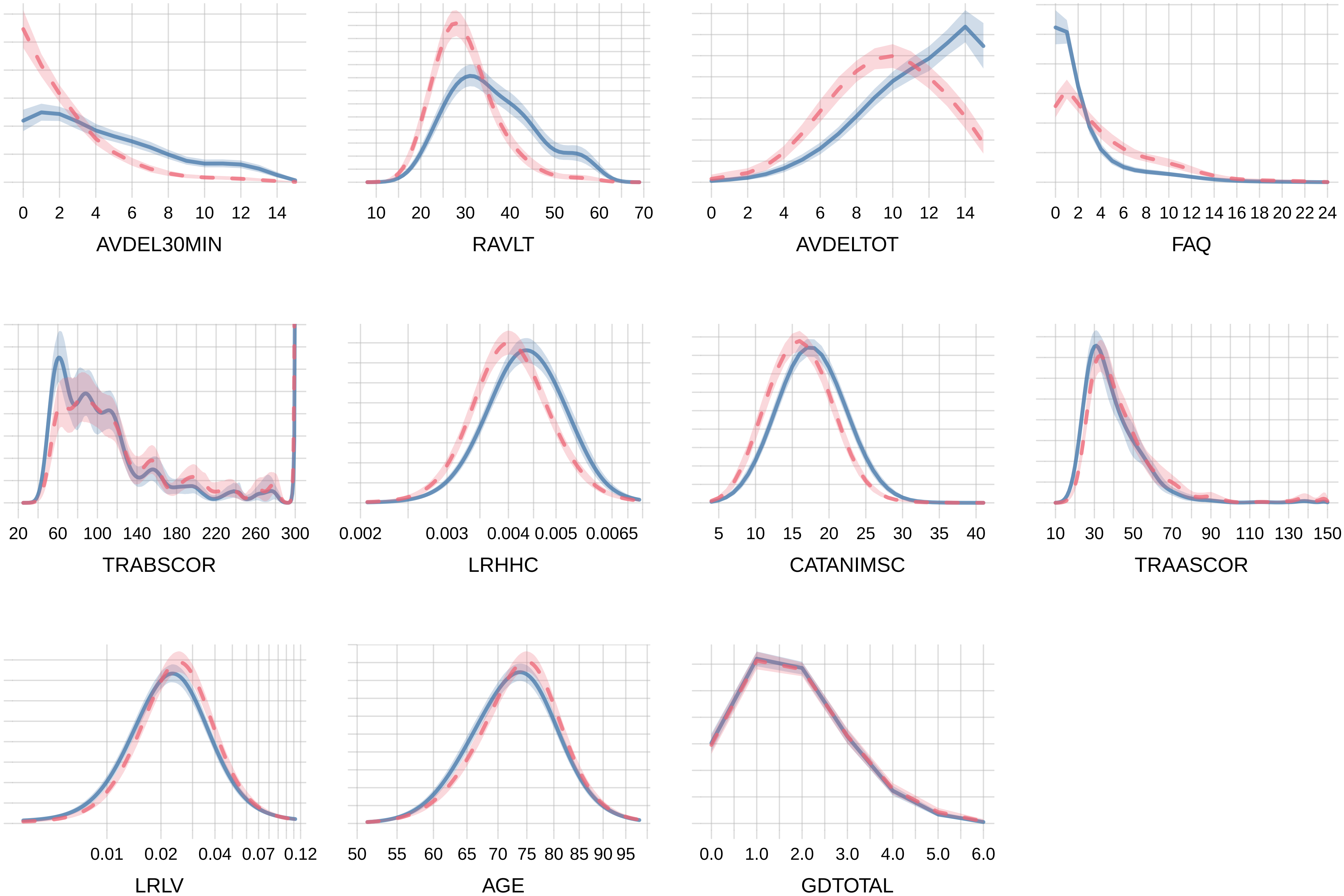


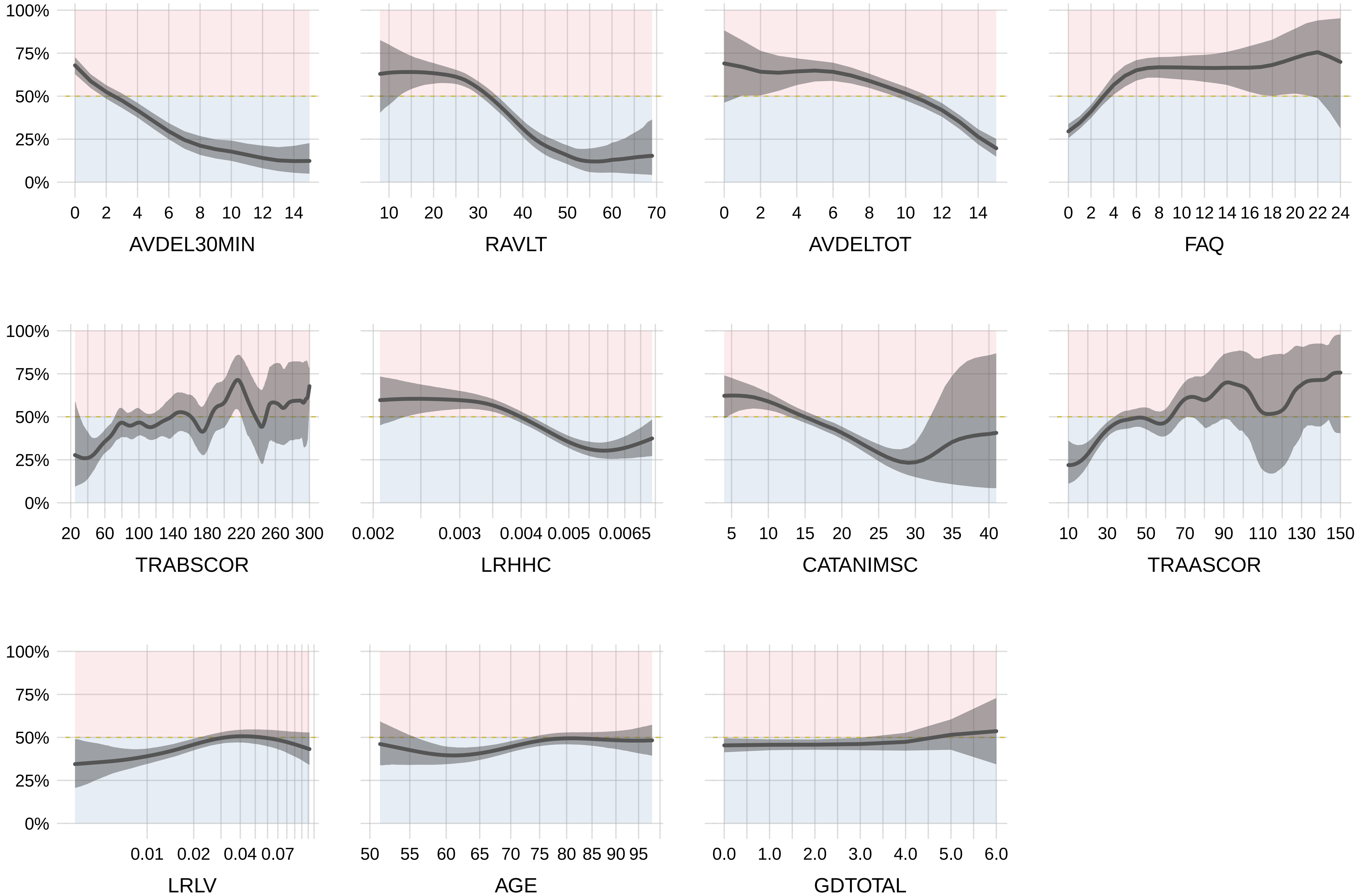


10 20 30 40 50 60 70
RAVLT
0 2 4 6 8 10 12 14
AVDEL30MIN
0 2 4 6 8 10 12 14
AVDELTOT
20 60 100 140 180 220 260 300
TRABSCOR
0.002 0.003 0.004 0.005 0.0065
LRHHC
5 10 15 20 25 30 35 40
CATANIMSC
10 30 50 70 90 110 130 150
TRAASCOR
0 5 10 15 20 25 30 35 40 45 50
ANARTERR
50 55 60 65 70 75 80 85 90 95
AGE
0 1
Apoe4
0 1
Gender
0.0 1.0 2.0 3.0 4.0 5.0 6.0
GDTOTAL




Probability of AD onset
100%
75%
50%
25%
0%
10 20 30 40 50 60 70
RAVLT
0 2 4 6 8 10 12 14
AVDEL30MIN
0 2 4 6 8 10 12 14
AVDELTOT
20 60 100 140 180 220 260 300
TRABSCOR
0.002 0.003 0.004 0.0055 0.0075
LRHHC
5 10 15 20 25 30 35 40
CATANIMSC
10 30 50 70 90 110 130 150
TRAASCOR
0 5 10 15 20 25 30 35 40 45 50
ANARTERR
50 55 60 65 70 75 80 90 100
AGE
0 1
Apoe4
0 1
Gender
0.0 1.0 2.0 3.0 4.0 5.0 6.0
GDTOTAL


0 2 4 6 8 10 12 14
AVDEL30MIN
10 20 30 40 50 60 70
RAVLT
0 2 4 6 8 10 12 14
AVDELTOT
0 2 4 6 8 10 12 14 16 18 20 22 24
FAQ
20 60 100 140 180 220 260 300
TRABSCOR
0.002 0.003 0.004 0.005 0.0065
LRHHC
5 10 15 20 25 30 35 40
CATANIMSC
10 30 50 70 90 110 130 150
TRAASCOR
0.01 0.02 0.04 0.07 0.12
LRLV
50 55 60 65 70 75 80 85 90 95
AGE
0.0 1.0 2.0 3.0 4.0 5.0 6.0
GDTOTAL



100%
75%
50%
25%
0%
0 2 4 6 8 10 12 14
AVDEL30MIN
10 20 30 40 50 60 70
RAVLT
0 2 4 6 8 10 12 14
AVDELTOT
0 2 4 6 8 10 12 14 16 18 20 22 24
FAQ
20 60 100 140 180 220 260 300
TRABSCOR
0.002 0.003 0.004 0.005 0.0065
LRHHC
5 10 15 20 25 30 35 40
CATANIMSC
10 30 50 70 90 110 130 150
TRAASCOR
0.01 0.02 0.04 0.07
LRLV
50 55 60 65 70 75 80 85 90 95
AGE
0.0 1.0 2.0 3.0 4.0 5.0 6.0
GDTOTAL

How to quantify the 'prognostic power' of a set of features?

Prediction problem:

guess the six digits of the winning lottery ticket ??????

Clue A: ✔✔✔✔??

Clue B: ✔✔✔?✔?

Clue C: ???✔✔✔

What is the 'importance' or 'predictive power' of each clue?

Scenario 1: we can use **only one** clue

Clue **A**: ✔✔✔✔??

Clue **B**: ✔✔✔?✔?

Clue **C**: ???✔✔✔

increasing importance

Best: **A** or **B** (each gives 1/81 winning chance)

Worst: **C** (gives 1/729 winning chance)

Scenario 2: we can use **all** clues

Clue **A**: ✔✔✔✔??

Clue **B**: ✔✔✔?✔?

Clue **C**: ???✔✔✔

→ We fully know the winning number! 💰

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✔✔✔✔??

Clue **B**: ✔✔✔?✔?

Clue **C**: ???✔✔✔

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✓✓✓✓??

Clue **B**: ✓✓✓?✓?

Clue **C**: ???✓✓✓

- Discard **A**: still 100% win ⇒ **A** has 'importance = **0**'

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✔✔✔✔??

Clue **B**: ✔✔✔?✔?

Clue **C**: ???✔✔✔

- Discard **A**: still 100% win $\Rightarrow$ **A** has 'importance = **0**'
- Discard **B**: still 100% win $\Rightarrow$ **B** has 'importance = **0**'

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✓✓✓✓??

Clue **B**: ✓✓✓?✓?

Clue **C**: ???✓✓✓

- Discard **A**: still 100% win $\Rightarrow$ **A** has ‘importance = **0**’
- Discard **B**: still 100% win $\Rightarrow$ **B** has ‘importance = **0**’

- Discard **A** *and* **B**: 1/9 winning chance

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✔✔✔✔??
Clue **B**: ✔✔✔?✔?
Clue **C**: ???✔✔✔

- Discard **A**: still 100% win $\Rightarrow$ **A** has ‘importance $=$ **0**’
- Discard **B**: still 100% win $\Rightarrow$ **B** has ‘importance $=$ **0**’

- Discard **A** *and* **B**: 1/9 winning chance

$\Rightarrow$ **A** and **B** together have ‘importance $>$ **0**’

Scenario 2: what happens if we **discard** clues?

Clue **A**: ✓✓✓✓??

Clue **B**: ✓✓✓?✓?

Clue **C**: ???✓✓✓

- Discard **A**: still 100% win $\Rightarrow$ **A** has 'importance = **0**'
- Discard **B**: still 100% win $\Rightarrow$ **B** has 'importance = **0**'

- Discard **A** *and* **B**: 1/9 winning chance

$\Rightarrow$ **A** and **B** together have 'importance > **0**'

$$\text{`}\, 0 + 0 \neq 0 \,\text{'}$$

‘Importance’ or ‘predictive power’ is *not* an *additive* property

Scenario 3: we have to **discard one** clue. Which?

Clue **A**: ✓✓✓✓??
Clue **B**: ✓✓✓?✓?
Clue **C**: ???✓✓✓

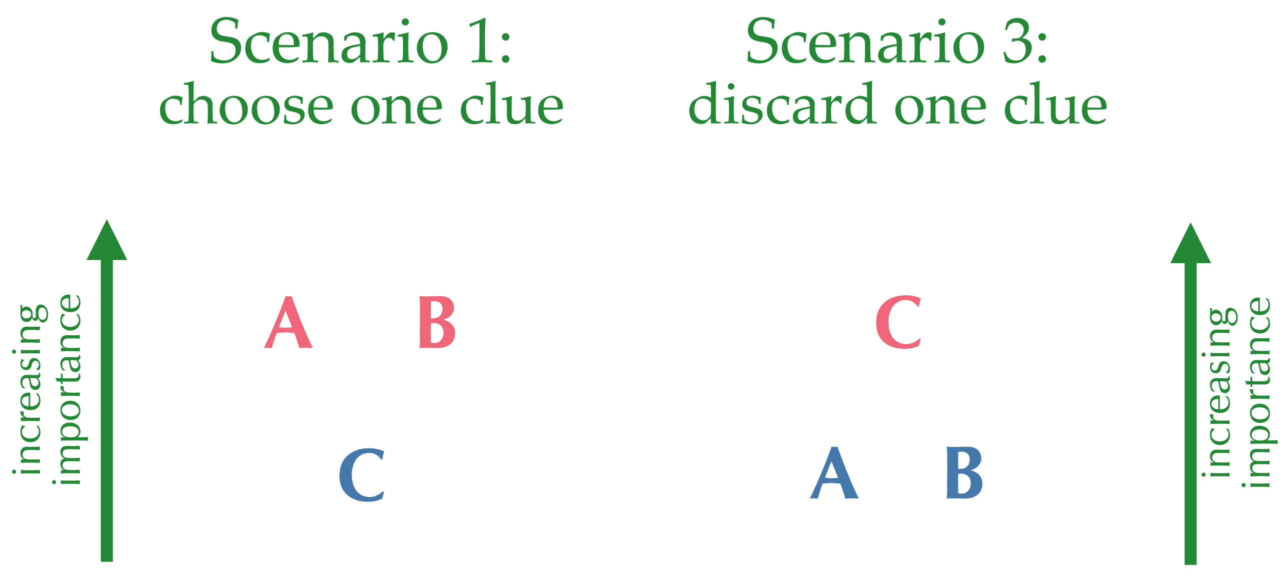
increasing importance

discard **A**: still 100% win

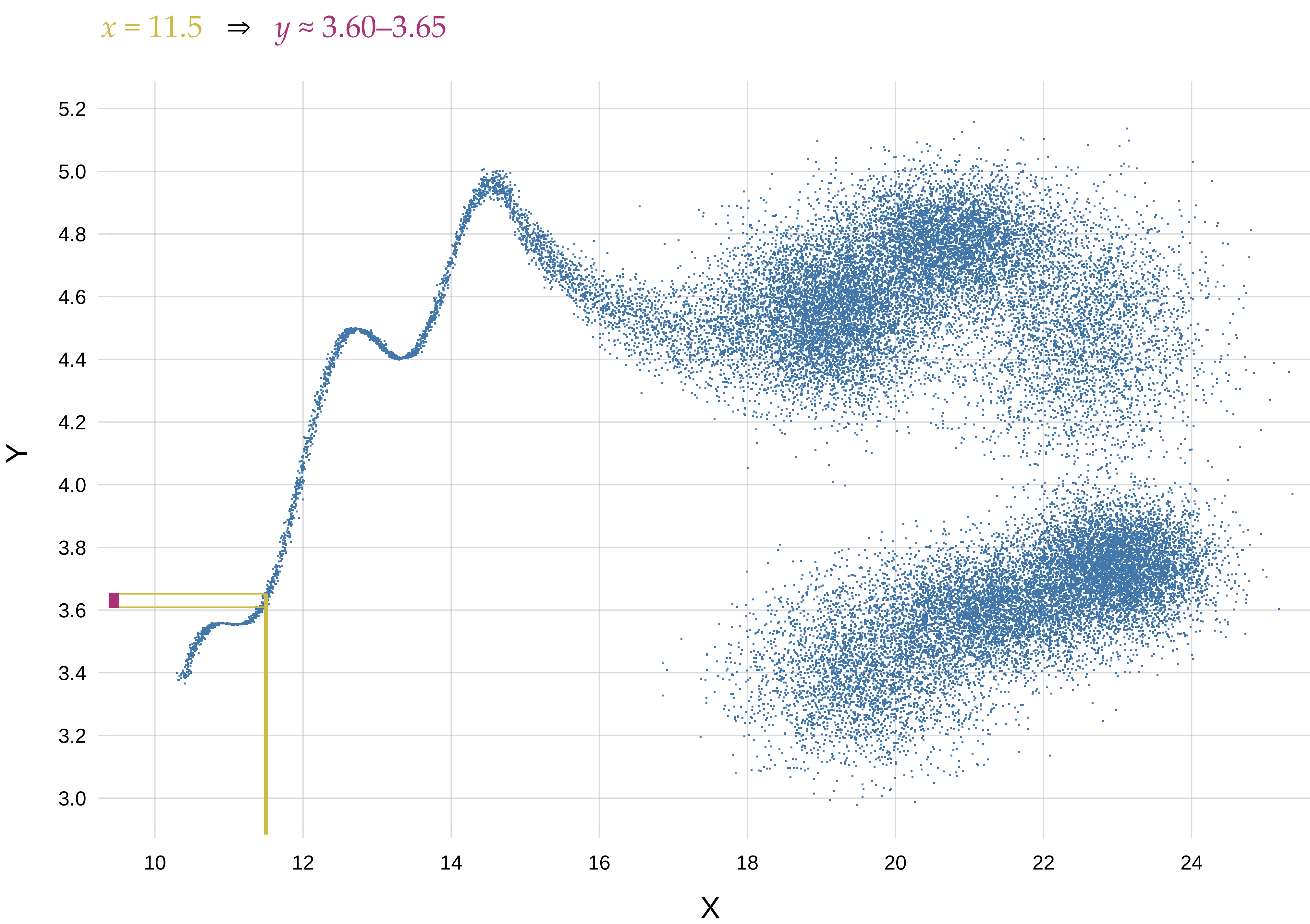
discard **B**: still 100% win

discard **C**: 1/9 winning chance

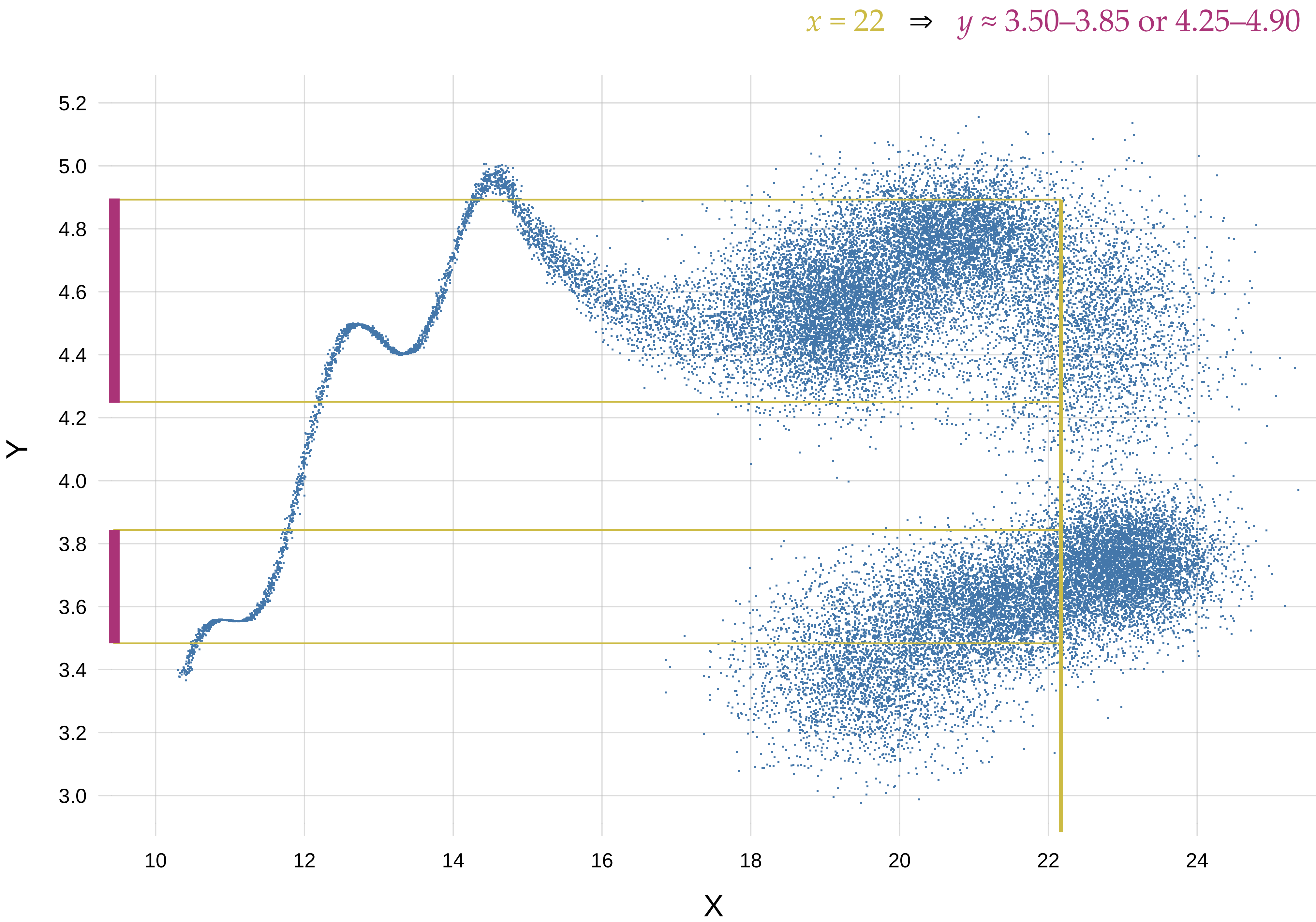
→ If we have to discard one clue, it’s most important that we keep **C**


Scenario 1:
choose one clue
Scenario 3:
discard one clue
increasing
importance
A
B
C
C
A
B
increasing
importance

‘Importance’ or ‘predictive power’ is *context-dependent*

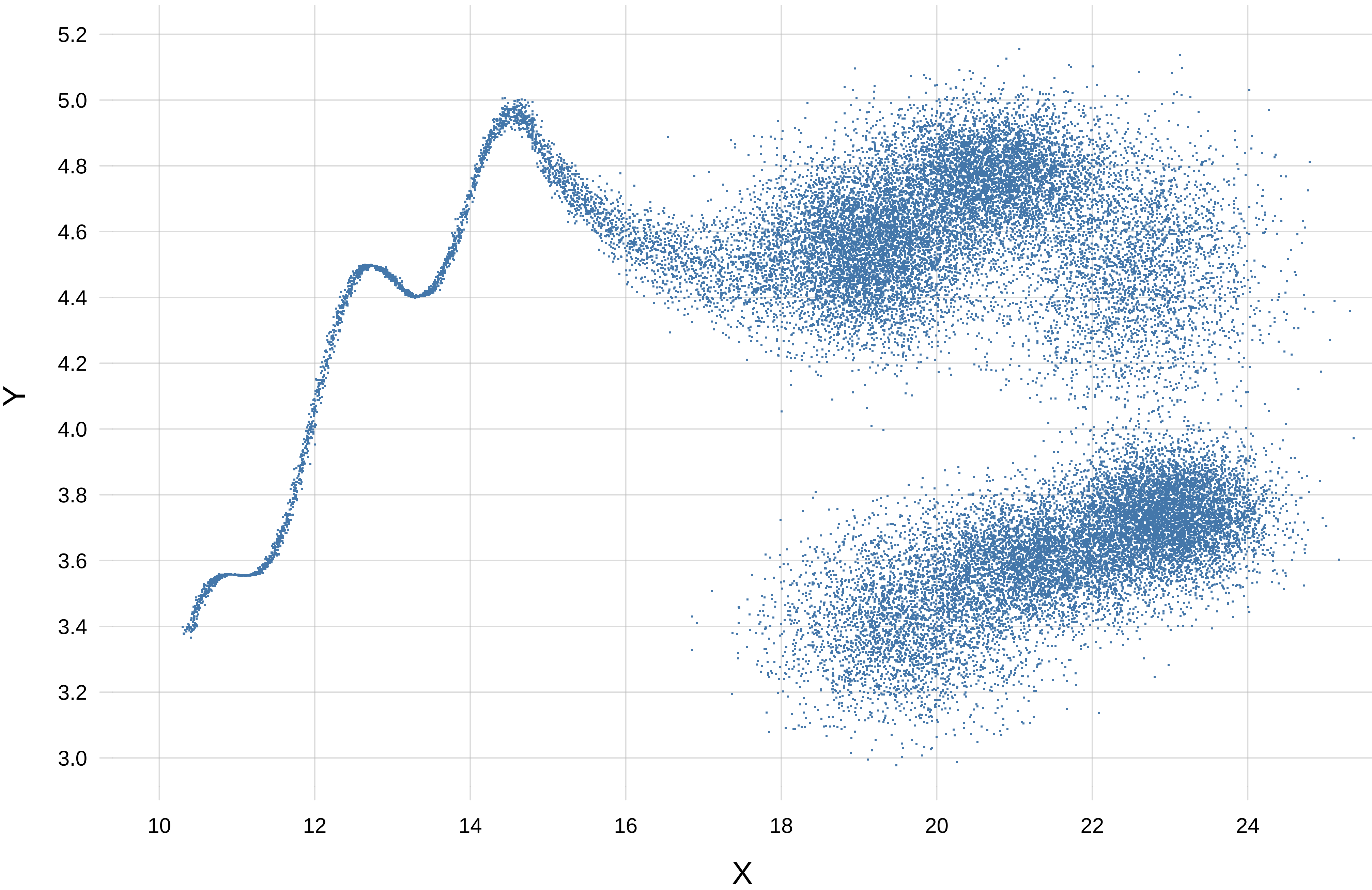


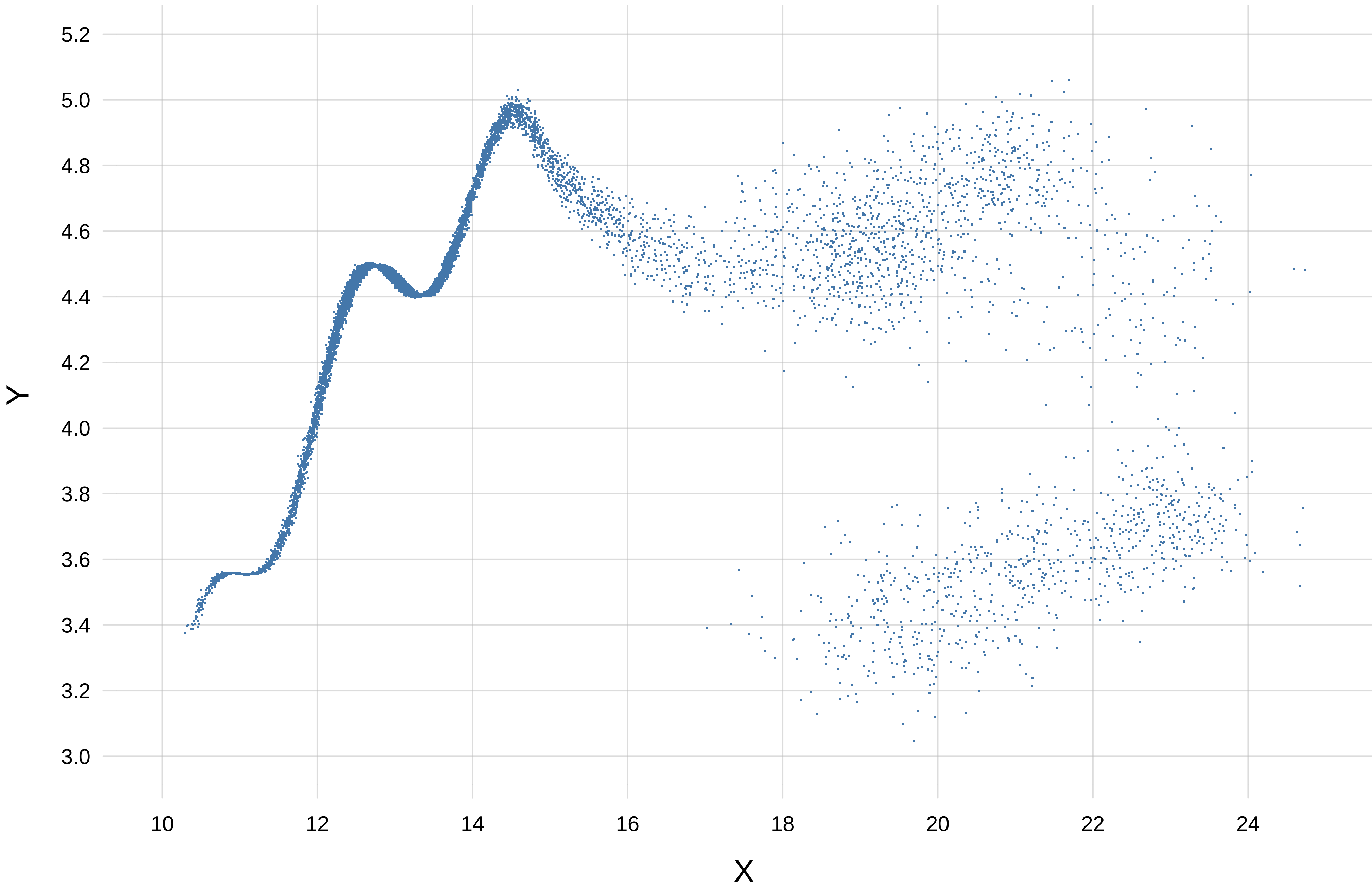
$x = 11.5 \Rightarrow y \approx 3.60–3.65$
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X

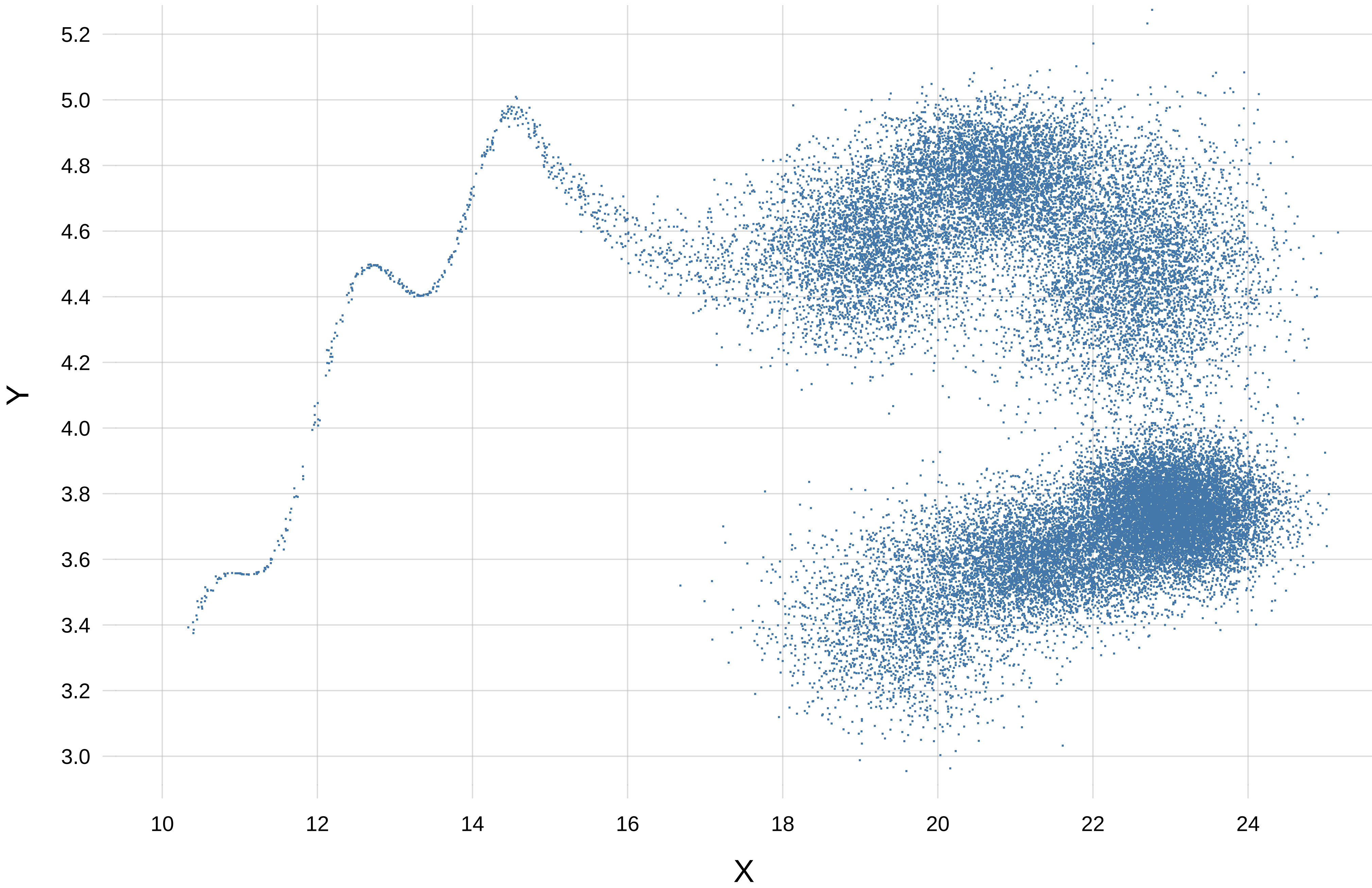


$x = 22 \Rightarrow y \approx 3.50–3.85$ or $4.25–4.90$
Y
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
10
12
14
16
18
20
22
24
X

What is the 'overall predictive power' of X?




5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X



5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Y
10
12
14
16
18
20
22
24
X

The ‘predictive power’ of X depends on $\mathrm{P}(X)$

⚠ Careful with ‘balancing’! ⚠

Information Theory

The Bell System Technical Journal

Vol. XXVII *July, 1948* *No. 3*

A Mathematical Theory of Communication

By C. E. SHANNON

Introduction

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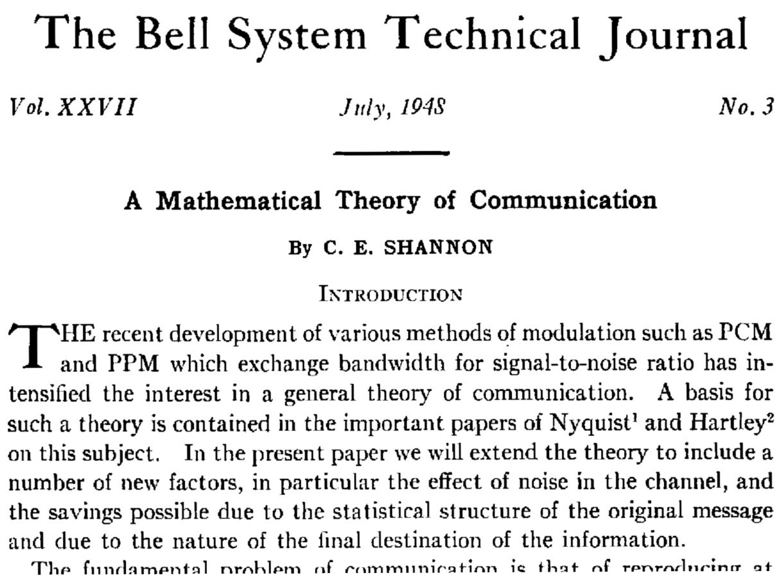
The fundamental problem of communication is that of reproducing at

Information Theory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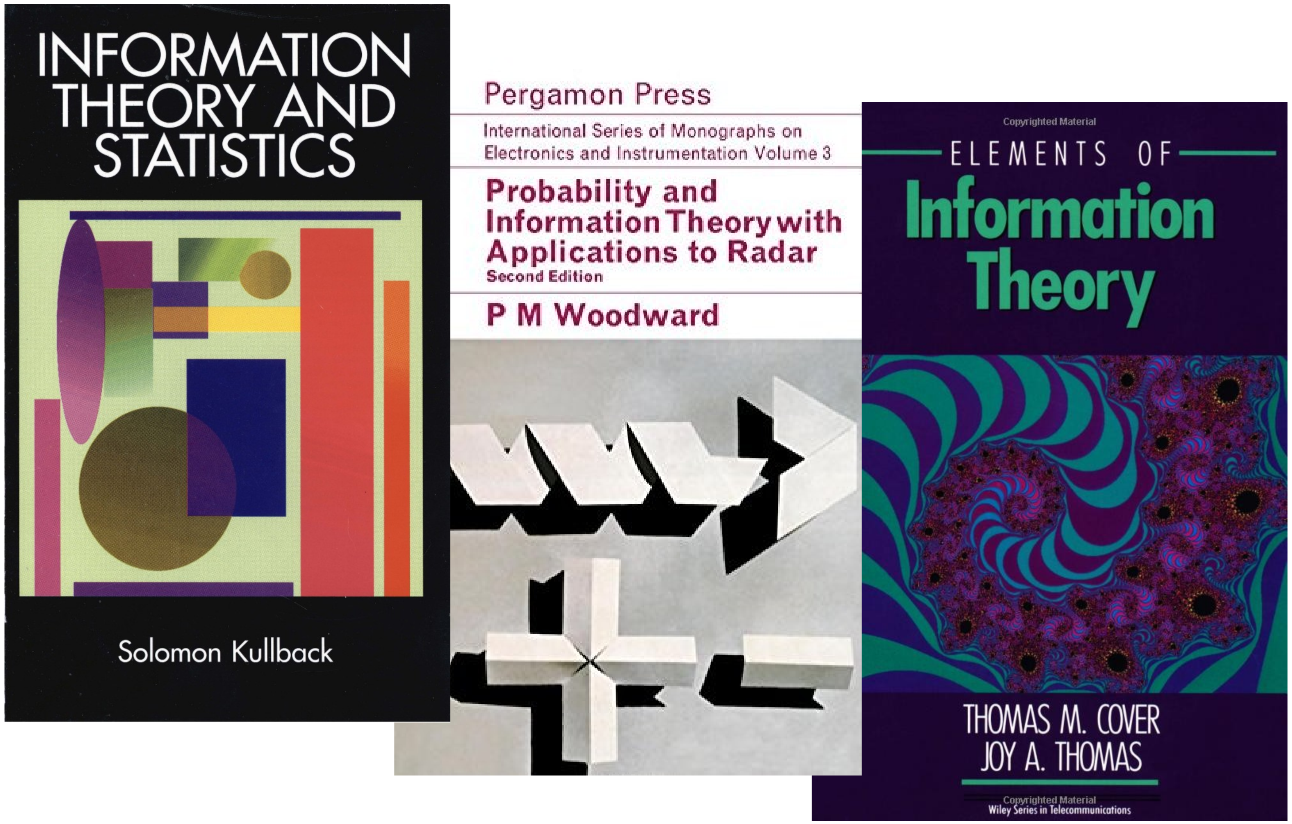
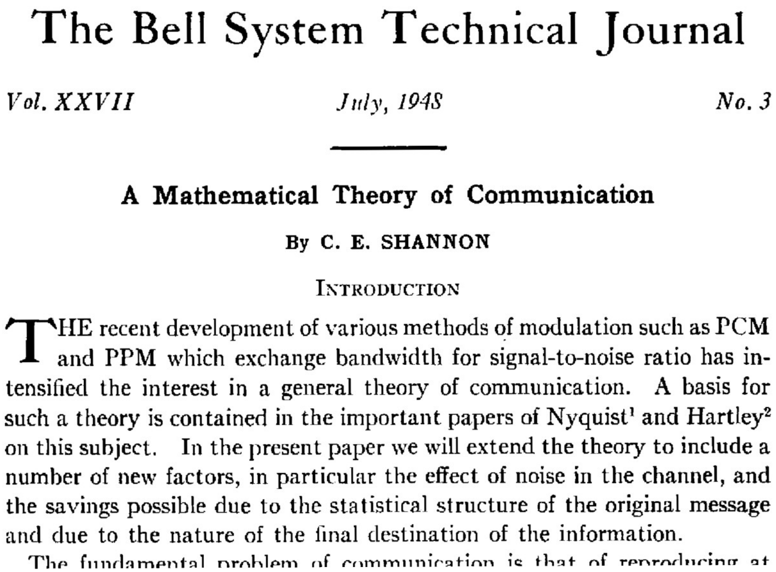


Information Theory



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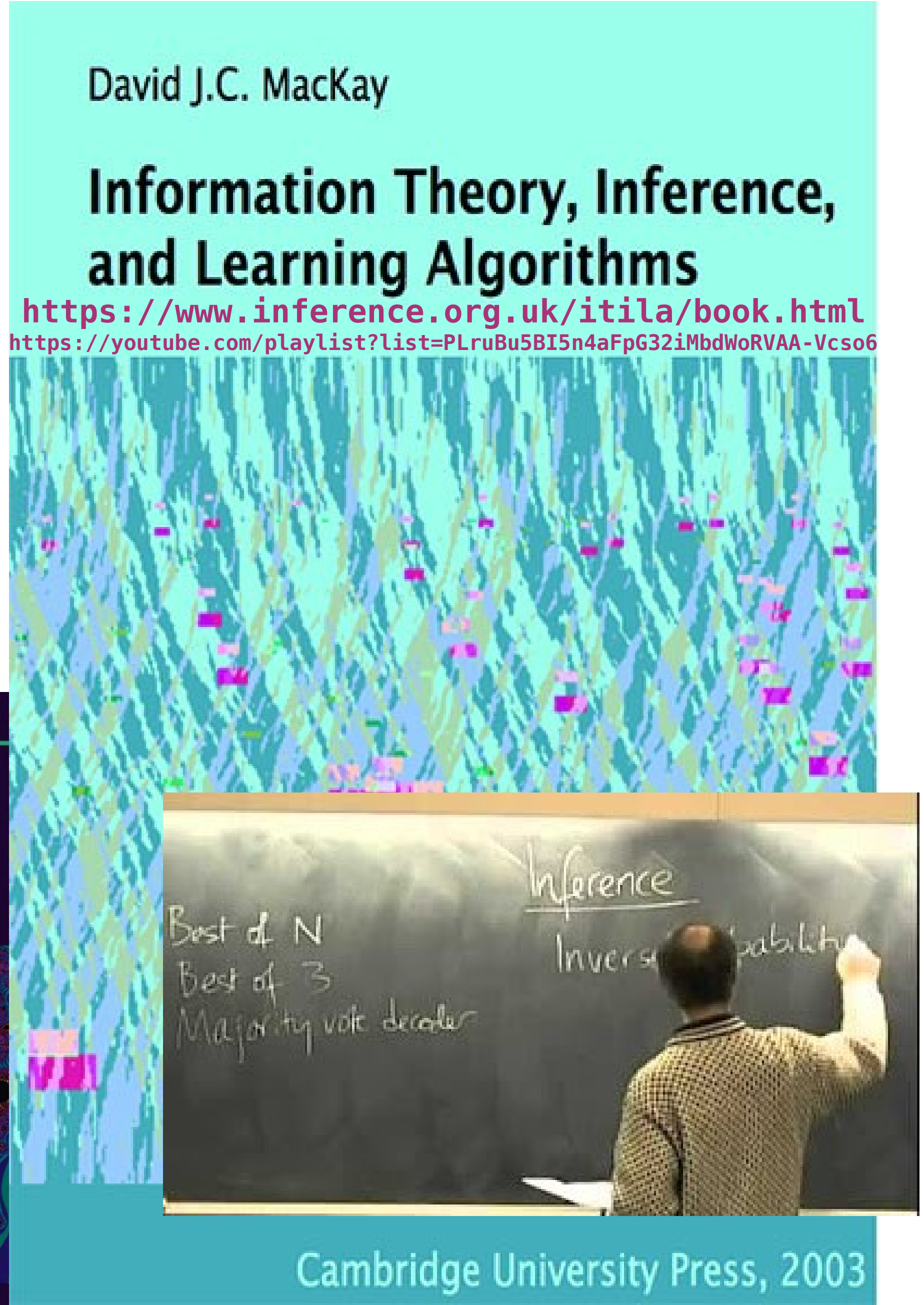
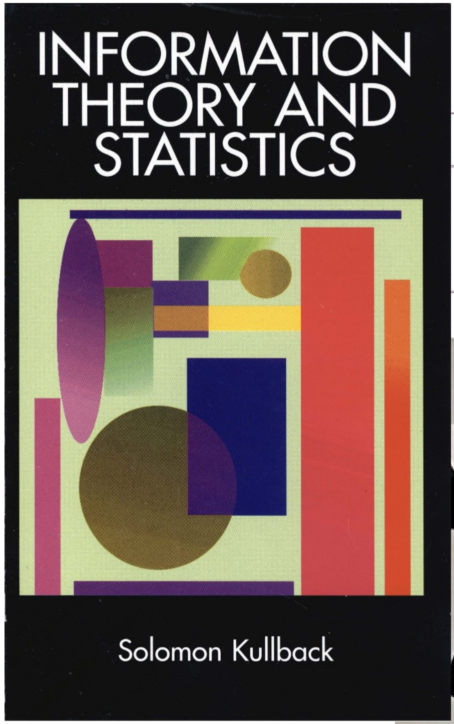
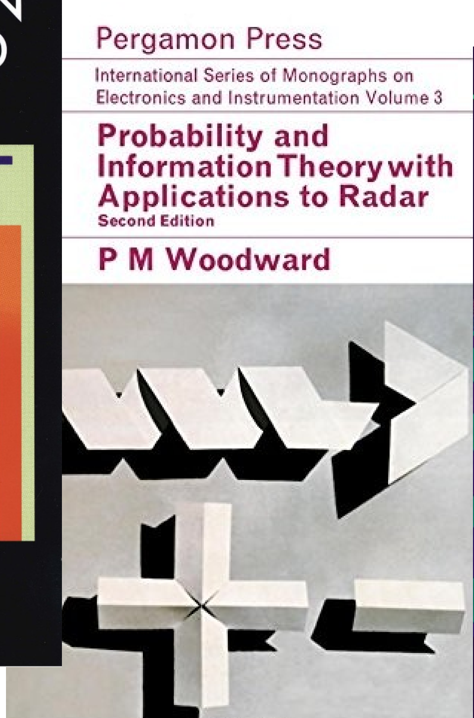
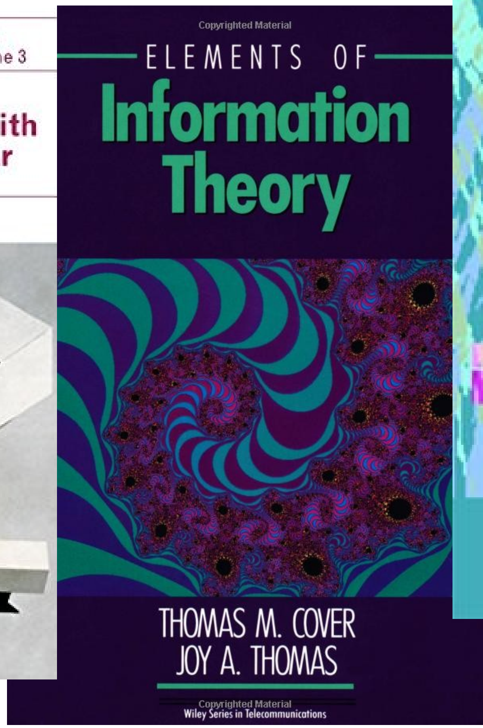
The fundamental problem of communication is that of reproducing at









‘predictive power’ of X for Y $\coloneqq$ **Mutual information** between Y and X
(mean transinformation content)

$$I(X;Y) := \int \mathrm{p}(y|\,x)\,\mathrm{p}(x)\;\log\left[\frac{\mathrm{p}(y|\,x)}{\mathrm{p}(y)}\right]\mathrm{d}y\,\mathrm{d}x$$

$$I(Y;\,X_1,\,X_2) \geq I(Y;\,X_1)$$

$$I(Y;\,X_1,\,X_2) \geq I(Y;\,X_2)$$

but $I(Y;\,X_1,\,X_2) \neq I(Y;\,X_1) + I(Y;\,X_2)$

IEC 80000-13

Edition 1.0 2008-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Quantities and units –
Part 13: Information science and technology

Grandeurs et unités –
Partie 13: Science et technologies de l'information

IEC | ISO

IEC 80000-13

Edition 1.0 2008-03

INTERNATIONAL STANDARD

INFORMATION SCIENCE AND TECHNOLOGY				QUANTITIES
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
13-24 (*902*)	information content *fr* *quantité* (f) *d'information*	$I(x)$	$I(x) = \mathrm{lb}\,\frac{1}{p(x)}$ Sh $= \lg \frac{1}{p(x)}$ Hart $= \ln \frac{1}{p(x)}$ nat where $p(x)$ is the probability of event x	See ISO/IEC 2382-16, item 16.03.02. See also IEC 60027-3.
13-25 (*903*)	entropy *fr* *entropie* (f)	H	$H(X) = \sum_{i=1}^{n} p(x_i) I(x_i)$ for the set $X = \{x_1, \ldots, x_n\}$ where $p(x_i)$ is the probability and $I(x_i)$ is the information content of event x_i	See ISO/IEC 2382-16, item 16.03.03.
13-30 (*908*)	joint information content *fr* *quantité* (f) *d'information conjointe*	$I(x, y)$	$I(x, y) = \mathrm{lb}\,\frac{1}{p(x, y)}$ Sh $= \lg \frac{1}{p(x, y)}$ Hart $= \ln \frac{1}{p(x, y)}$ nat where $p(x, y)$ is the joint probability of events x and y	
13-35 (*912*)	transinformation content *fr* *transinformation* (f)	$T(x, y)$	$T(x, y) = I(x) + I(y) - I(x, y)$ where $I(x)$ and $I(y)$ are the information contents (13-24) of events x and y, respectively, and $I(x, y)$ is their joint information content (13-30)	See ISO/IEC 2382-16, item 16.04.07.
13-36 (*913*)	mean transinformation content *fr* *transinformation* (f) *moyenne*	T	$T(X,Y) = \sum_{i=1}^{n} \sum_{j=1}^{m} p(x_i, y_j) T(x_i, y_j)$ for the sets $X = \{x_1, \ldots, x_n\}$, $Y = \{y_1, \ldots, y_m\}$, where $p(x_i, y_j)$ is the joint probability of events x_i and y_j, and $T(x_i, y_j)$ is their transinformation content (item 13-35)	See ISO/IEC 2382-16, item 16.04.08.

UNITS				INFORMATION SCIENCE AND TECHNOLOGY
Item No.	**Name**	**Symbol**	**Definition**	**Conversion factors and remarks**
13-24.a	shannon	Sh	value of the quantity when the argument is equal to 2	1 Sh ≈ 0,693 nat ≈ 0,301 Hart
13-24.b	hartley	Hart	value of the quantity when the argument is equal to 10	1 Hart ≈ 3,322 Sh ≈ 2,303 nat
13-24.c	natural unit of information	nat	value of the quantity when the argument is equal to e	1 nat ≈ 1,433 Sh ≈ 0,434 Hart
13-25.a	shannon	Sh		
13-25.b	hartley	Hart		
13-25.c	natural unit of information	nat		
13-30.a	shannon	Sh		
13-30.b	hartley	Hart		
13-30.c	natural unit of information	nat		
13-35.a	shannon	Sh		
13-35.b	hartley	Hart		
13-35.c	natural unit of information	nat		
13-36.a	shannon	Sh		In practice, the unit "shannon per character" is generally used, and sometimes the units "hartley per character" and "natural unit per character".
13-36.b	hartley	Hart		
13-36.c	natural unit of information	nat		

If Y is binary:

$$0\ \mathrm{Sh} \le I(Y;X) \le 1\ \mathrm{Sh}$$

$$\frac{1}{2} + \frac{1}{2}\sqrt{1-(1-0.22)^{\frac{4}{3}}} \approx 77\,\%$$

If Y is binary:

$$0\ \mathrm{Sh} \;\leq\; I(Y;X) \;\leq\; 1\ \mathrm{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

$$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\%$$

If Y is binary:

$$0\ \mathrm{Sh} \le I(Y;X) \le 1\ \mathrm{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

Y is a deterministic function of X
X always yields perfect predictions

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$$I(Y;X) = 0.22\ \text{Sh}$$

$$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\%$$

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Y is a deterministic function of X
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$$I(Y;X) = 0.22\ \mathrm{Sh}$$

In 100 new prognoses:

$$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\%$$

If Y is binary:

$$0\ \text{Sh} \le I(Y;X) \le 1\ \text{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

Y is a deterministic function of X
X always yields perfect predictions

$$I(Y;X) = 0.22\ \text{Sh}$$

In 100 new prognoses:

- we are **completely certain** about 22

$$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\%$$

If Y is binary:

$$0\ \mathrm{Sh} \le I(Y;X) \le 1\ \mathrm{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

Y is a deterministic function of X
X always yields perfect predictions

$$I(Y;X) = 0.22\ \mathrm{Sh}$$

In 100 new prognoses:

- we are **completely certain** about 22
- we are **completely uncertain** about $100 - 22 = 78$

$$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\%$$

If Y is binary:

$$0\ \mathrm{Sh} \leq I(Y;X) \leq 1\ \mathrm{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

Y is a deterministic function of X
X always yields perfect predictions

$$I(Y;X) = 0.22\ \mathrm{Sh}$$

In 100 new prognoses:

- we are **completely certain** about 22
- we are **completely uncertain** about $100 - 22 = 78$

$\rightarrow$ approx $22 + 78/2 = \mathbf{61}$ correct prognoses (TP+TN)

More precise bound: $$\frac{1}{2} + \frac{1}{2}\sqrt{1 - (1 - 0.22)^{\frac{4}{3}}} \approx 77\,\% \quad \pm 0.8\sqrt{N}\,\%$$ correct prognoses

If Y is binary:

$$0\ \mathrm{Sh} \le I(Y;X) \le 1\ \mathrm{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

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X always yields perfect predictions

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More precise bound: $$\frac{1}{2}+\frac{1}{2}\sqrt{1-(1-0.22)^{\frac{4}{3}}} \approx 77\,\% \quad \pm 0.8\sqrt{N}\,\%$$ correct prognoses

Maximum accuracy attainable

If Y is binary:

$$0\ \text{Sh} \leq I(Y;X) \leq 1\ \text{Sh}$$

X and Y are independent
Using X is no better than flipping a coin

Y is a deterministic function of X
X always yields perfect predictions

$$I(Y;X) = 0.22\ \text{Sh}$$

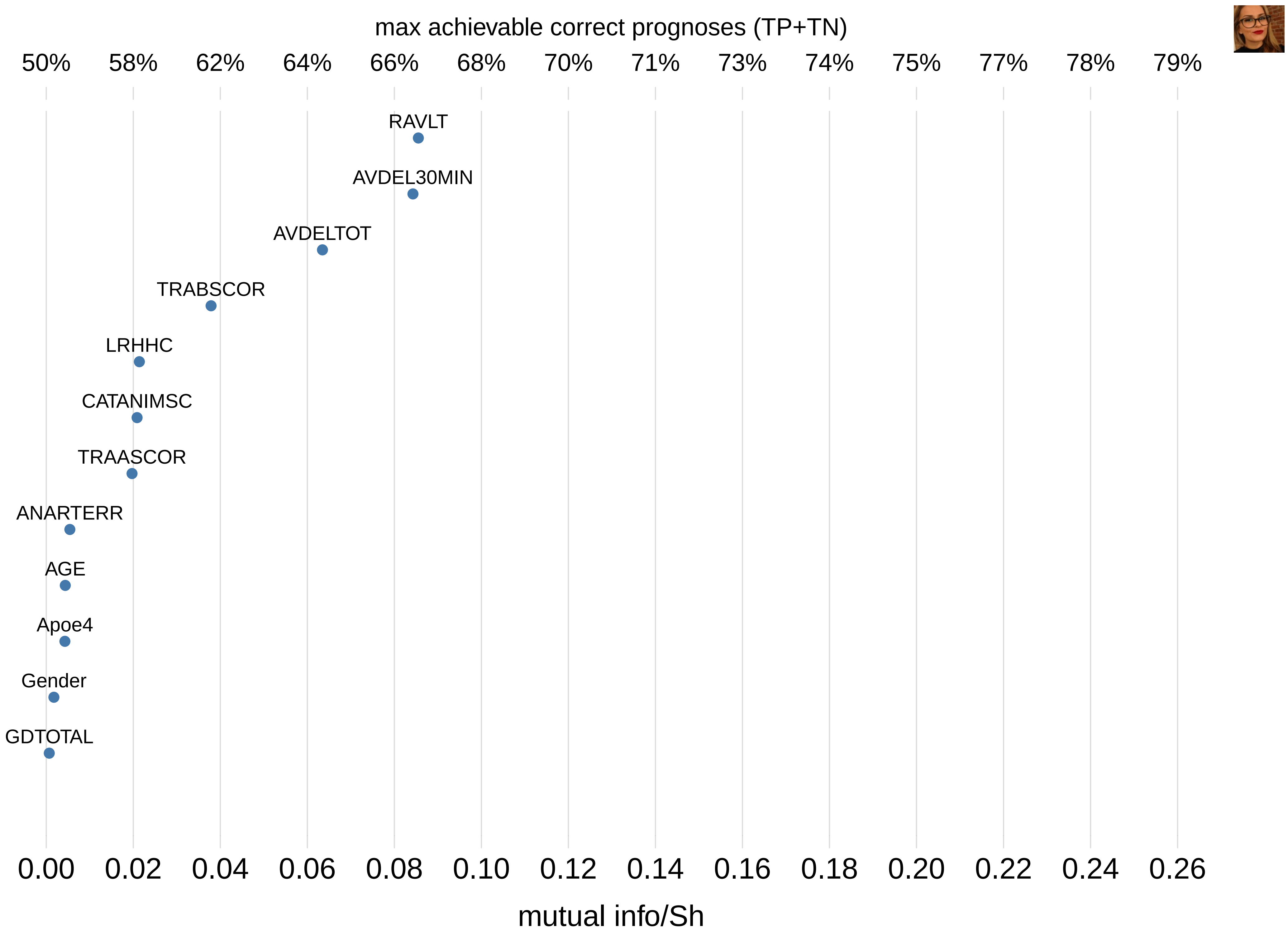
In 100 new prognoses:

- we are **completely certain** about 22
- we are **completely uncertain** about $100 - 22 = 78$

$\rightarrow$ approx $22 + 78/2 = \mathbf{61}$ correct prognoses (TP+TN)

More precise bound: $$\frac{1}{2} + \frac{1}{2}\sqrt{1-(1-0.22)^{\frac{4}{3}}} \approx 77\,\% \quad \pm 0.8\sqrt{N}\,\%$$ correct prognoses

Maximum accuracy attainable
by *any* algorithm which uses only feature set X



max achievable correct prognoses (TP+TN)
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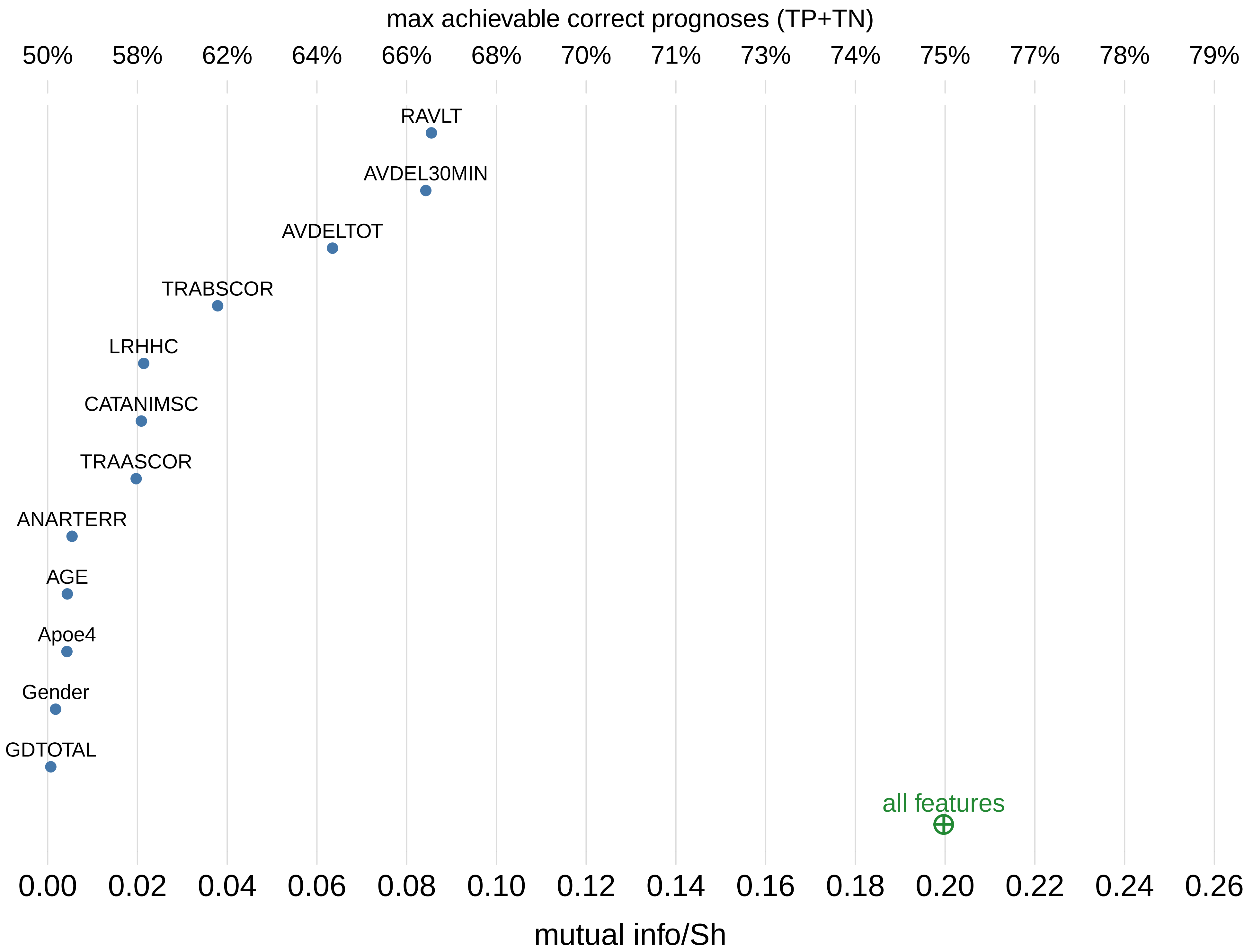
mutual info/Sh



max achievable correct prognoses (TP+TN)
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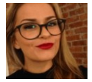

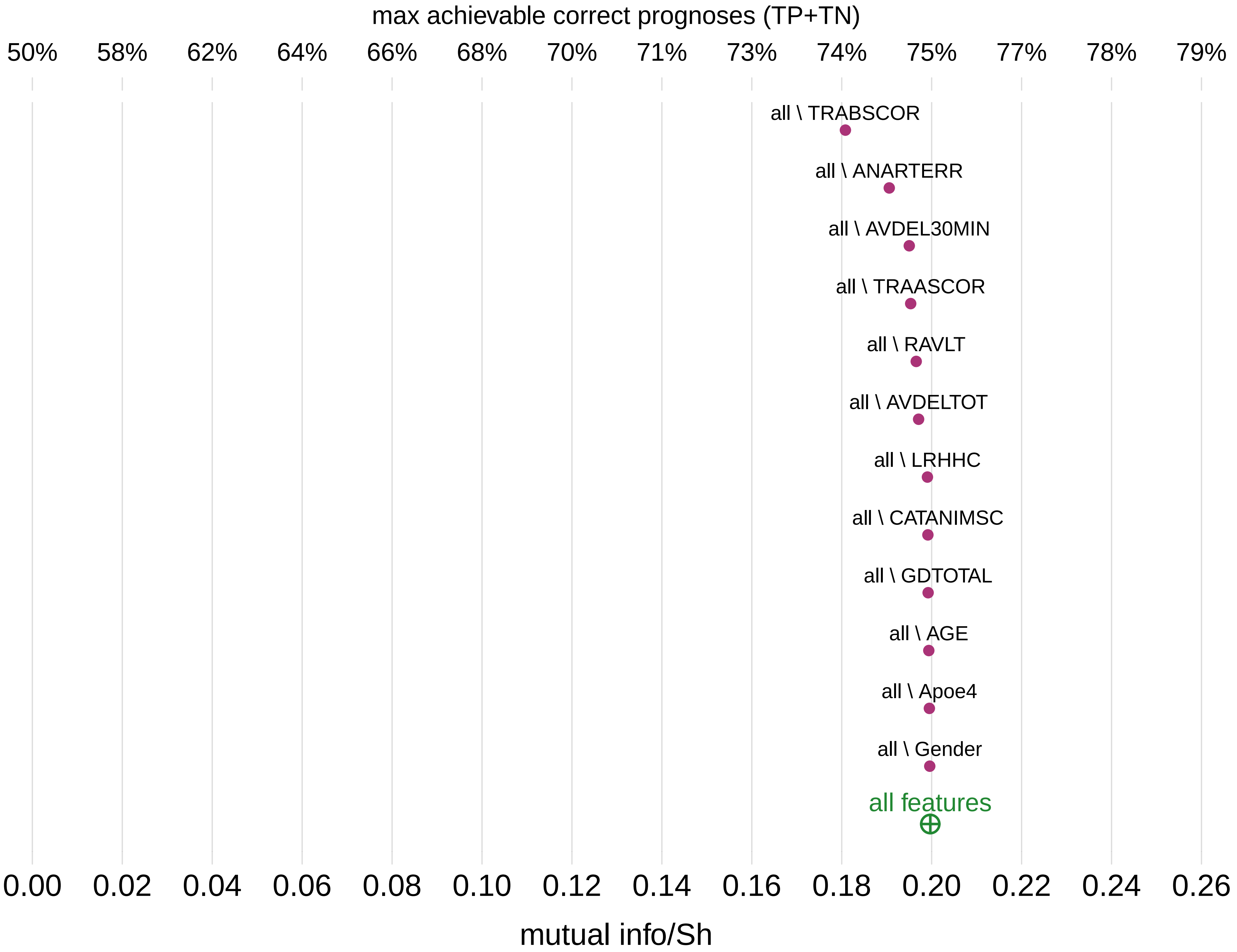

max achievable correct prognoses (TP+TN)
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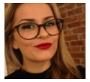

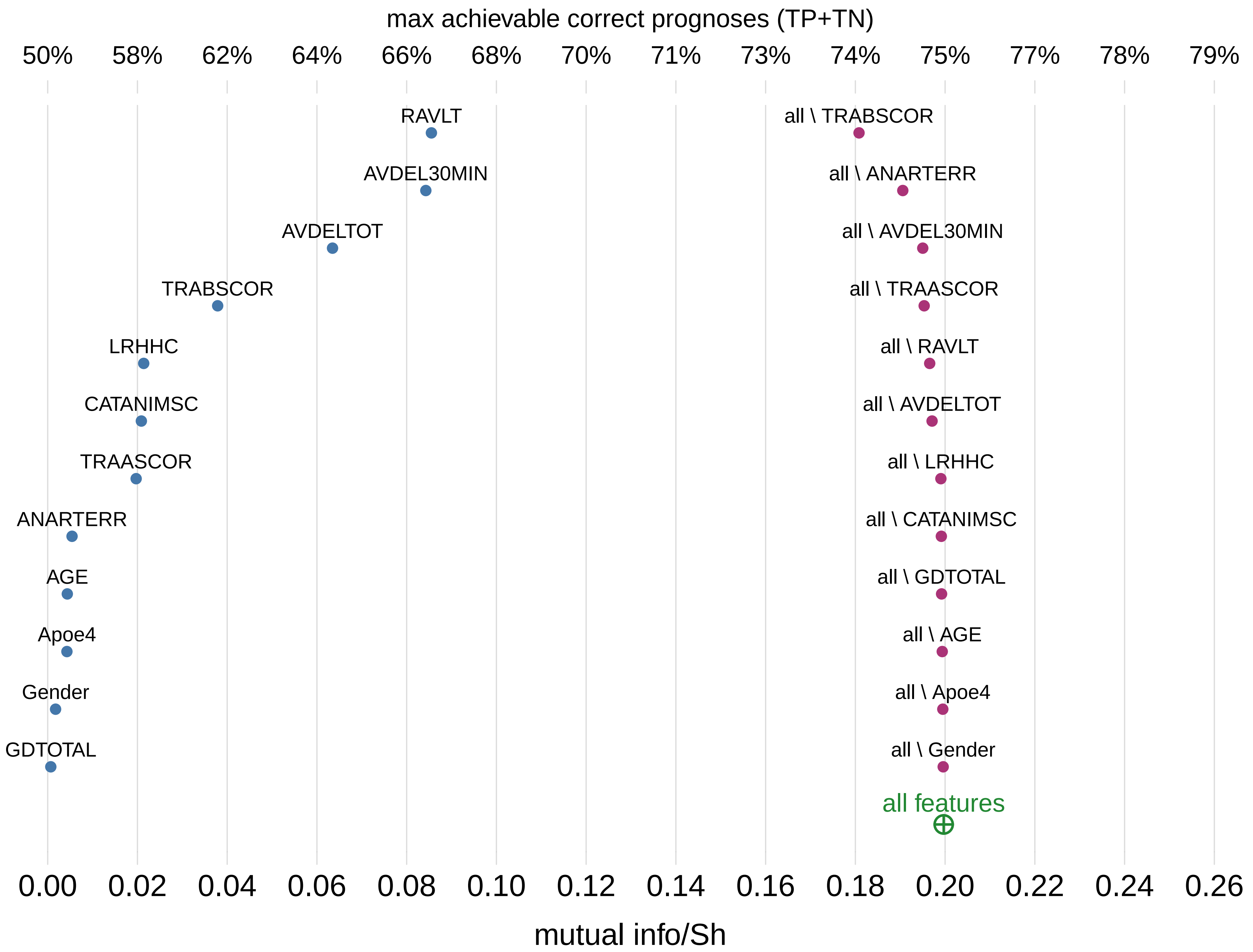

max achievable correct prognoses (TP+TN)
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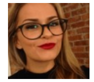

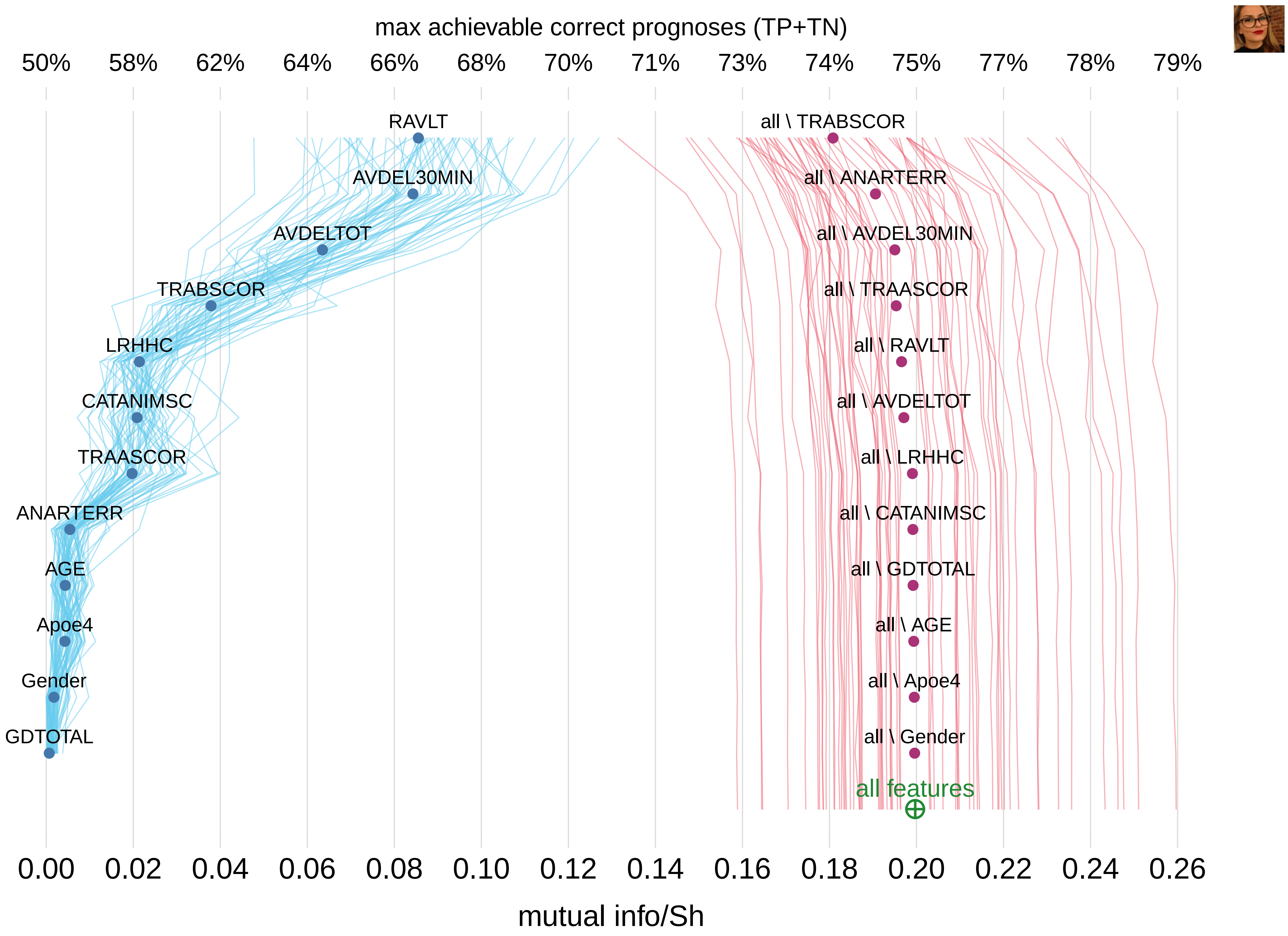
max achievable correct prognoses (TP+TN)
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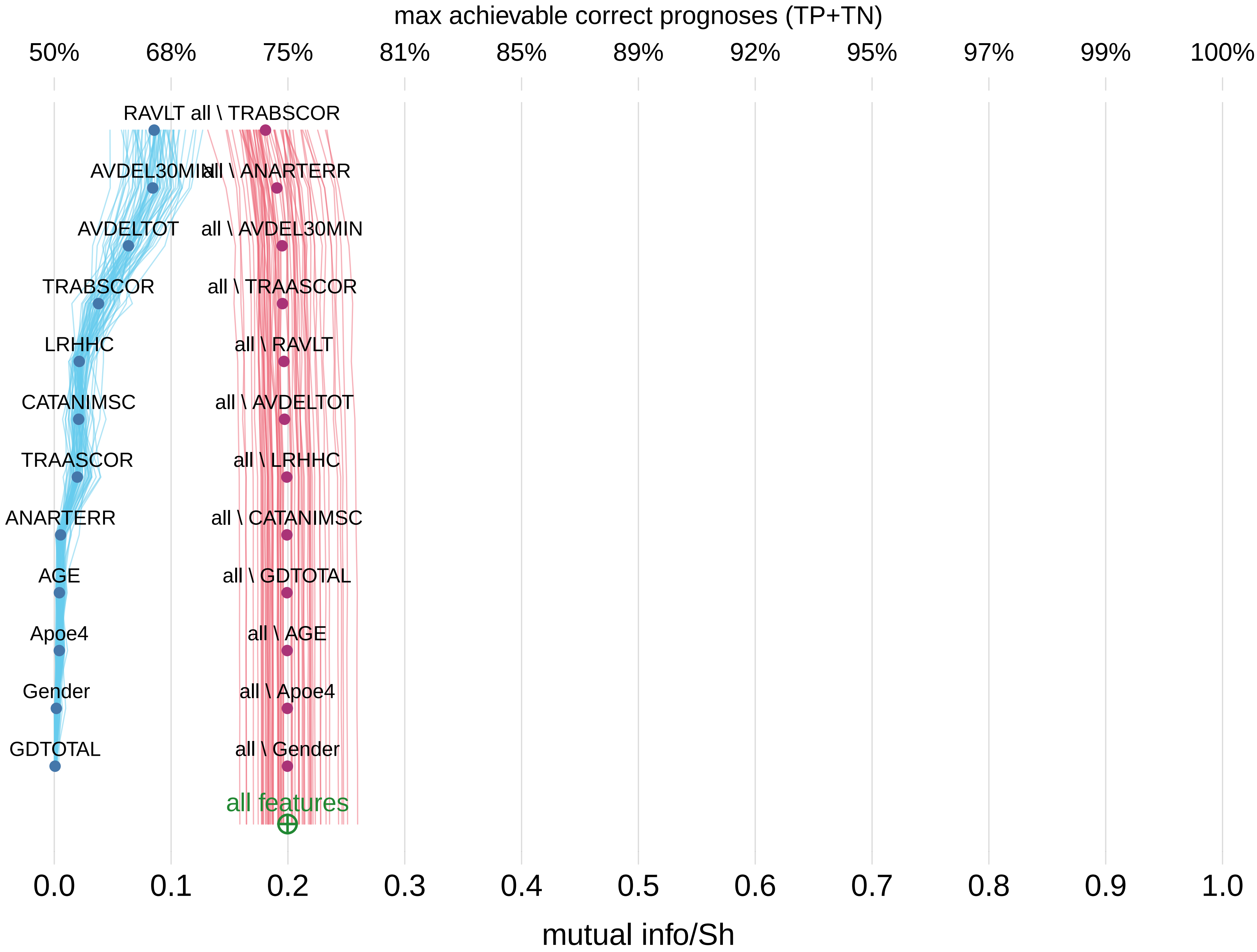

max achievable correct prognoses (TP+TN)
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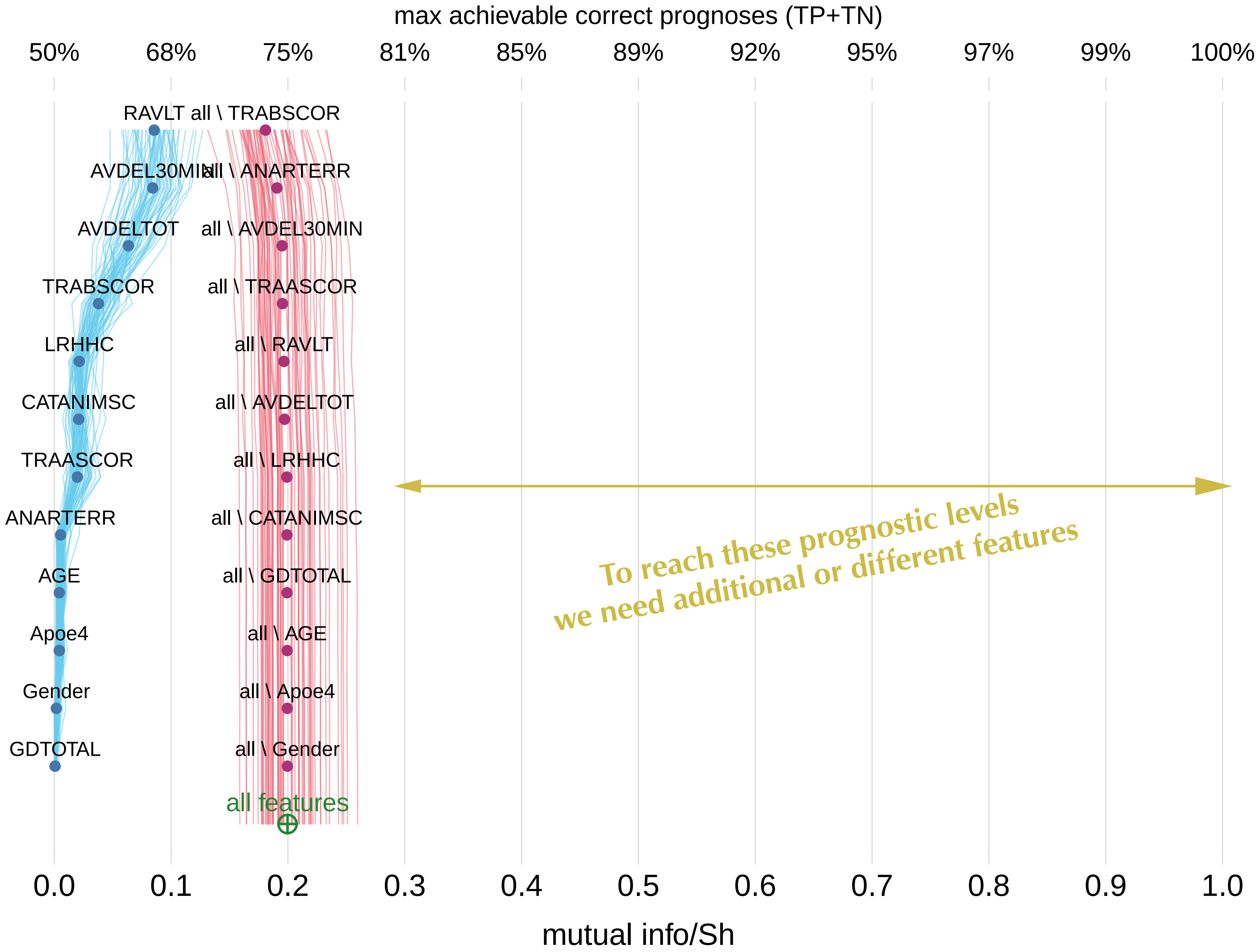

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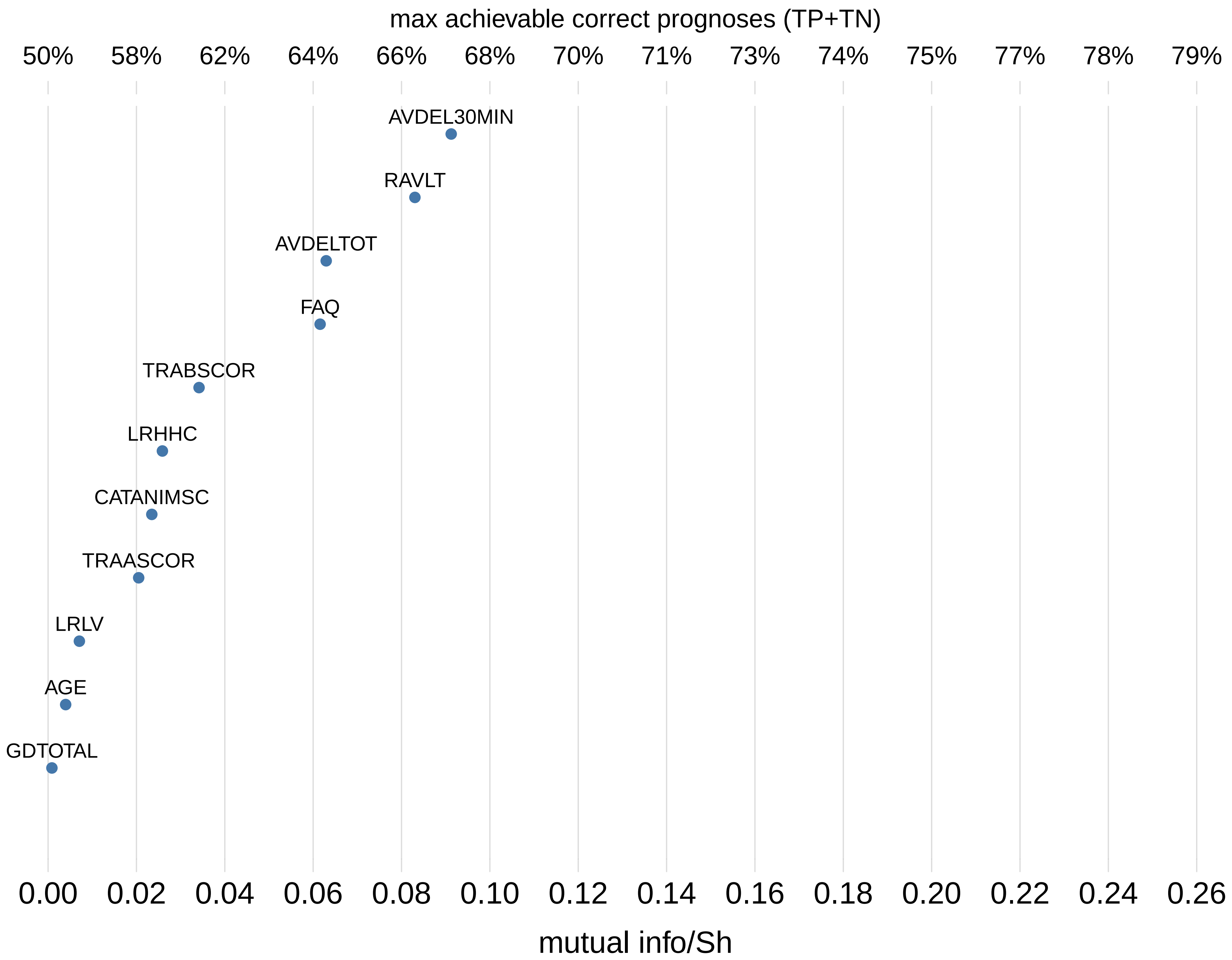

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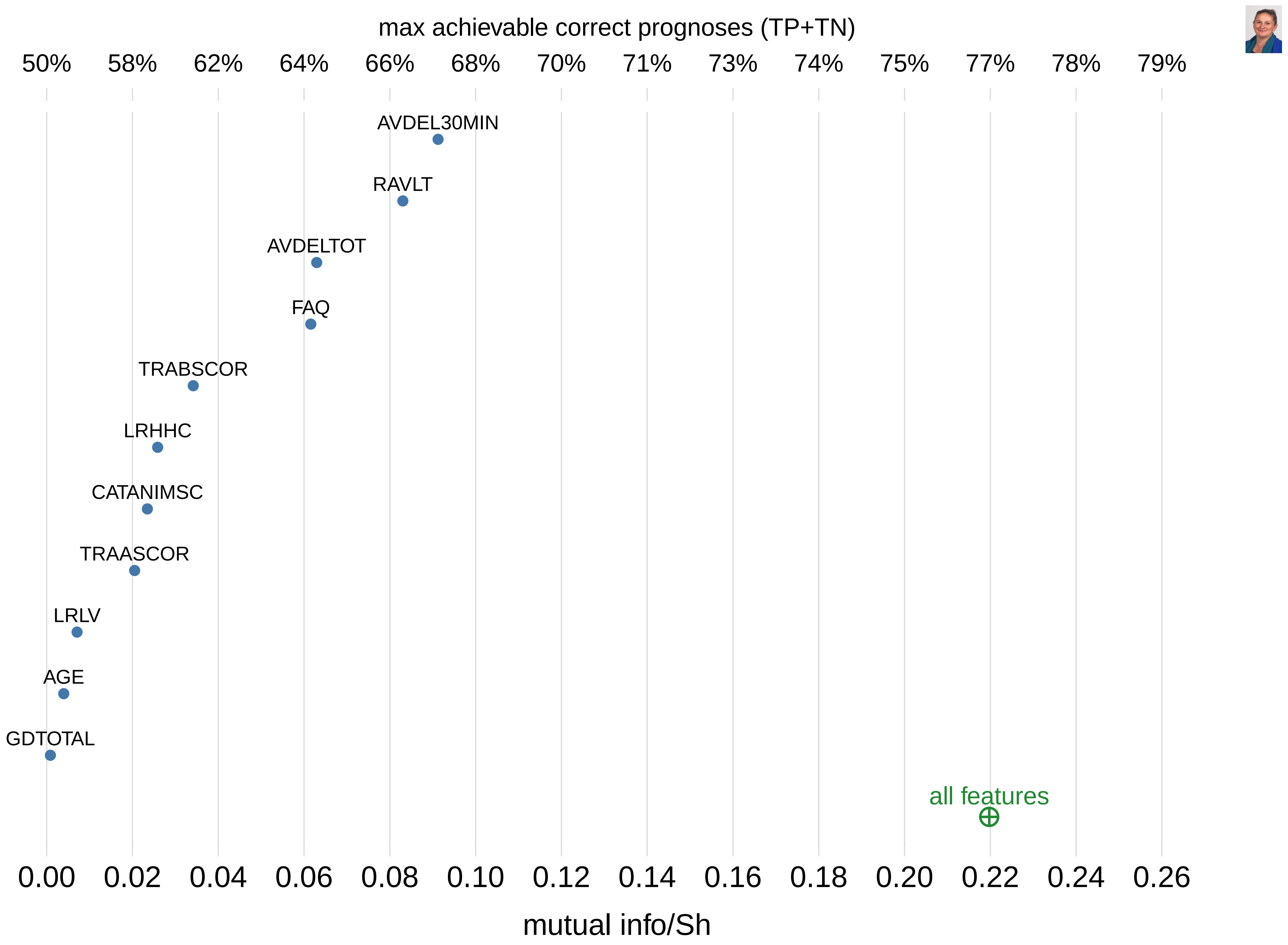
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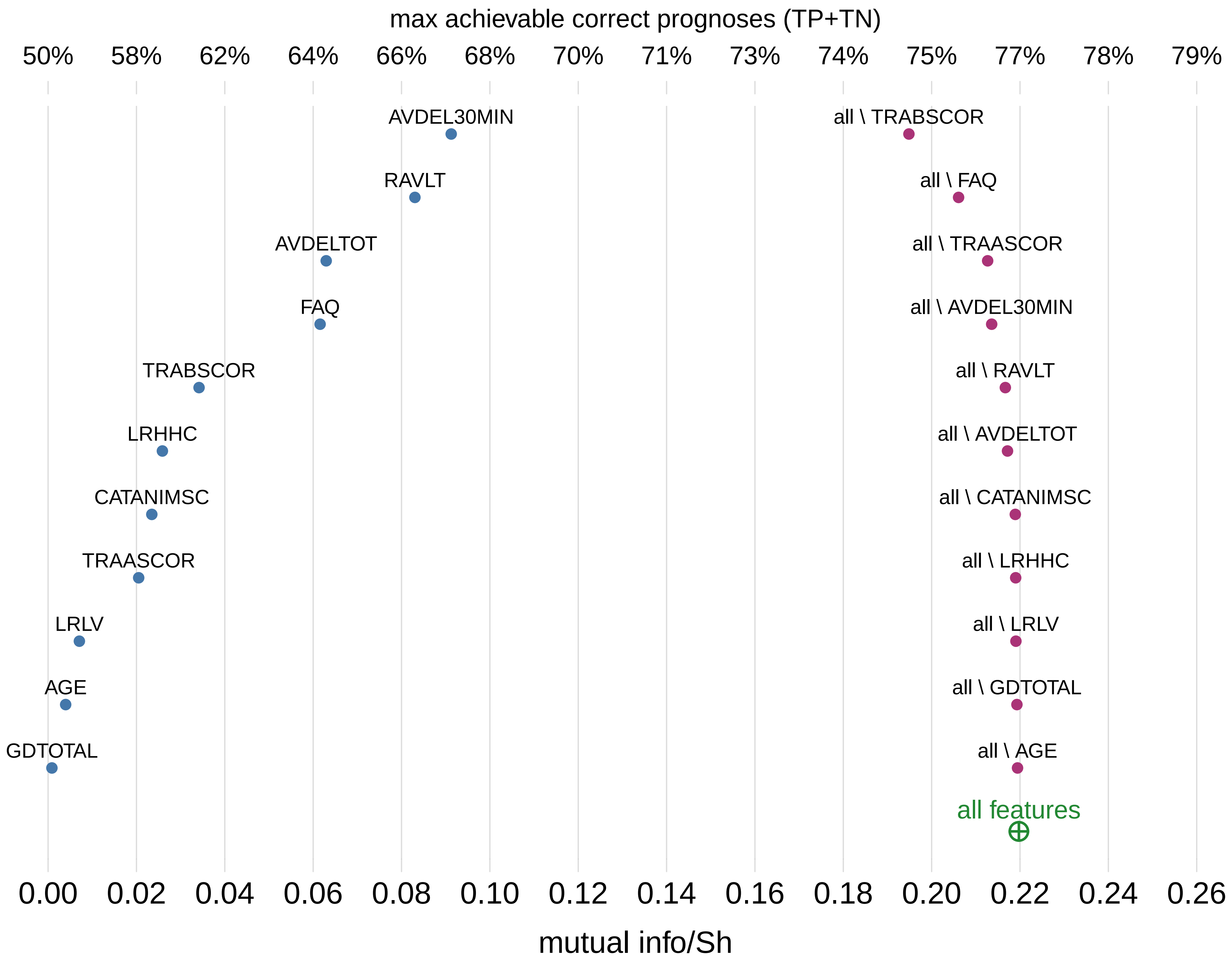
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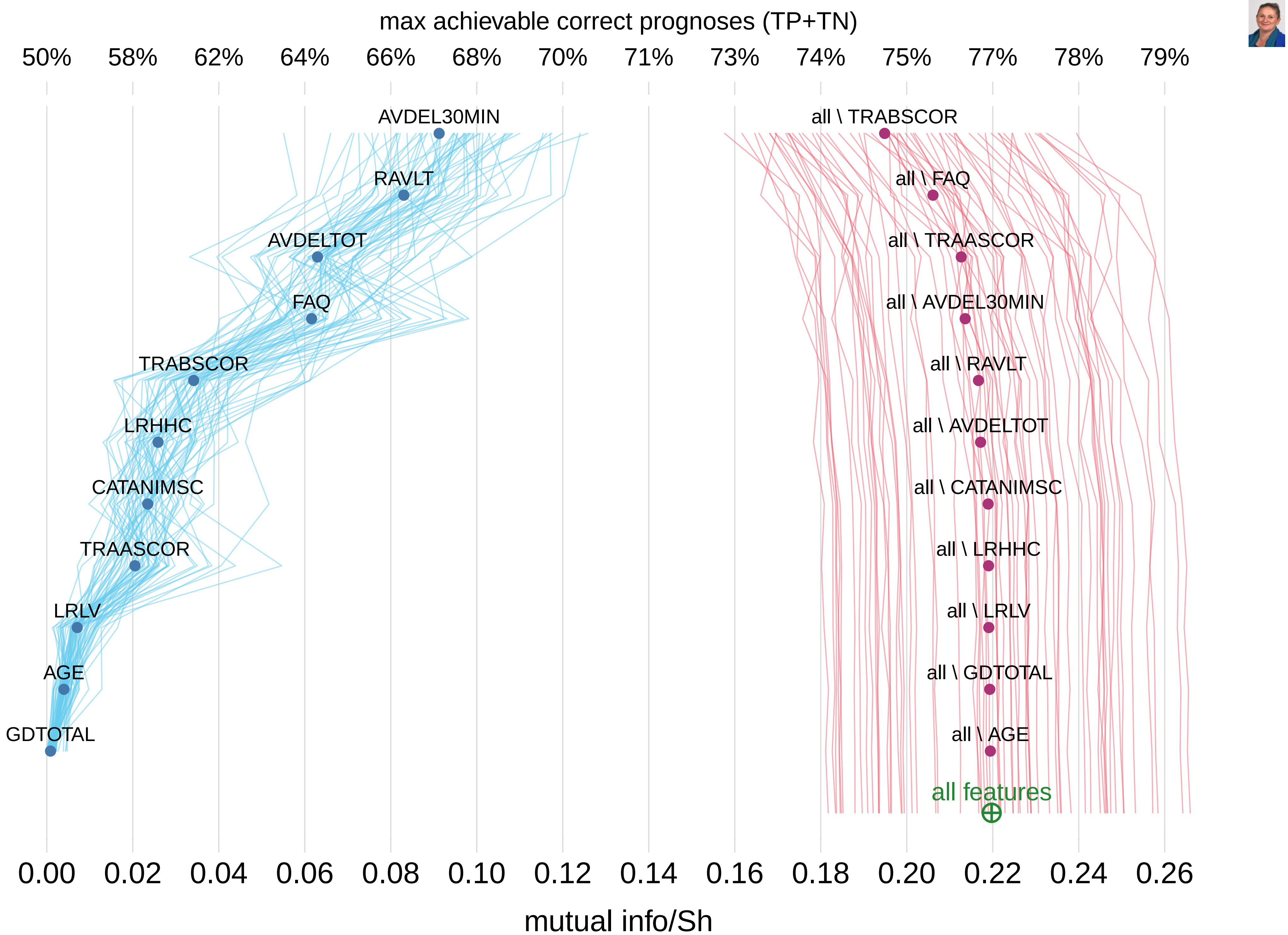
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mutual info/Sh