Is Your Dark Energy Theory Falsifiable?

Andreas Albrecht (UC Davis)

DarkFun 2007, LBL

Jan 19 2007

➔ How can you test your DE theory?

➔ How can you estimate the testability of a given theory when you with proposed new data

1) Direct comparison with data

1) A “quick and dirty” approach

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How well do Dark Energy Task Force simulated data sets constrain specific scalar field quintessence models?

Augusta Abrahamse

Brandon Bozek

Michael Barnard

+AA

+

DETF
Simulated data

+

Quintessence
potentials

+

MCMC

See also Dutta & Sorbo 2006

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Why now?

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Why now?

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Brando

Michae

+AA

ata

→ State impact of future experiments

→ Input to designing future expts?

potentials

MCMC

See also Dutta & Sorbo 2006

How well do Dark Energy Task Force simulated data sets constrain specific scalar field quintessence models?

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+AA

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ta

In progress

+

sence

potentials

+

MCMC

See also Dutta & Sorbo 2006

The potentials

Exponential (Wetterich, Peebles & Ratra)

PNGB (Frieman et al)

Exponential with prefactor (AA & Skordis)

The potentials

Exponential (Wetterich, Peebles & Ratra)

$$\boxed{V(\varphi) = V_0 e^{-\lambda\varphi}}$$

PNGB (Frieman et al)

$$\boxed{V(\varphi) = V_0(\cos(\varphi/\lambda)+1)}$$

Exponential with prefactor (AA & Skordis)

$$\boxed{V(\varphi) = V_0\left(\chi\left(\varphi-\beta\right)^2+\delta\right)e^{-\lambda\varphi}}$$

& others

The potentials

Exponential (Wetterich, Peebles & R

Brandon

$$\boxed{V(\varphi) = V_0 e^{-\lambda\varphi}}$$

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Augusta

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Exponential with prefactor (AA & Skordis)

Michael

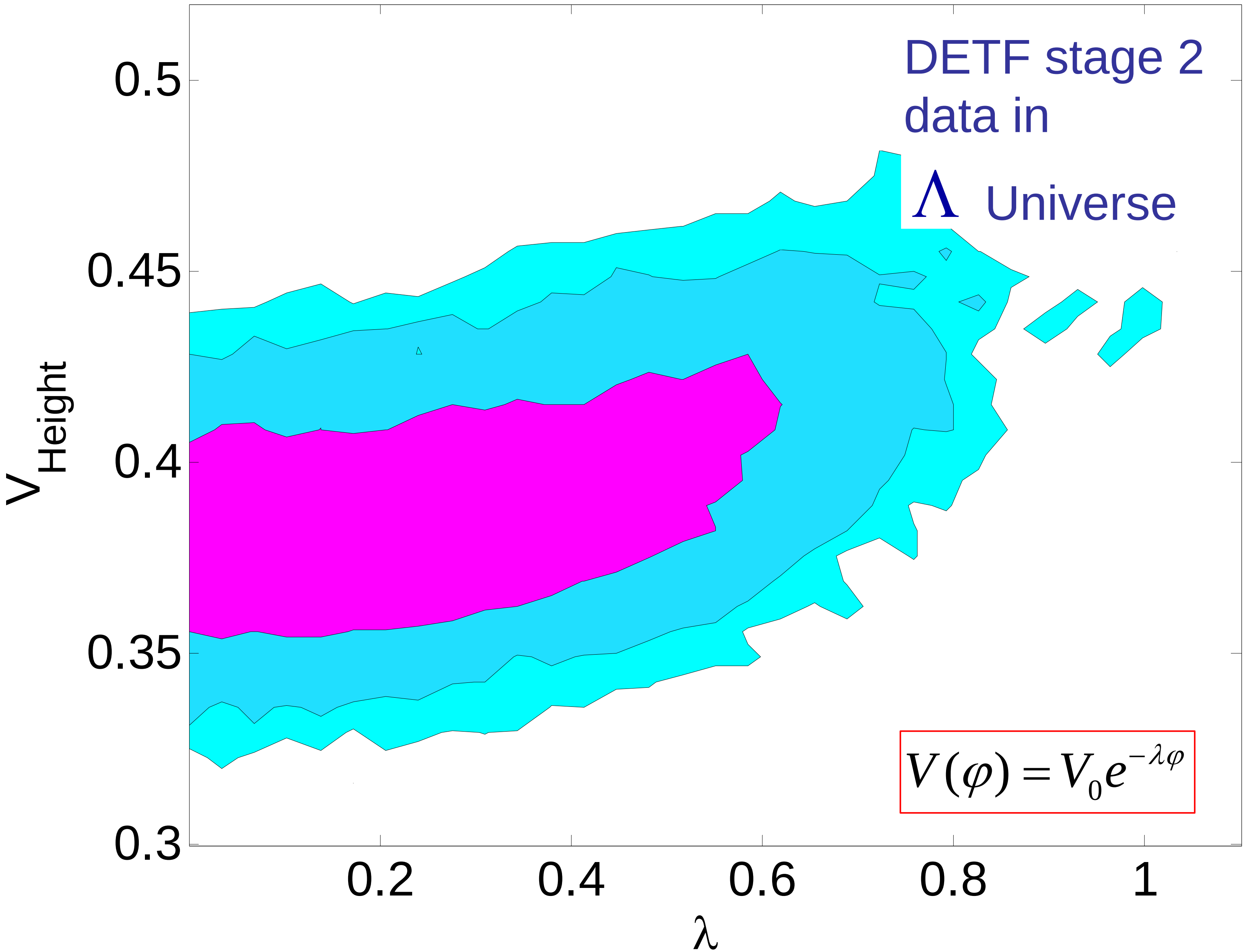
$$\boxed{V(\varphi) = V_0\left(\chi(\varphi - \beta)^2 + \delta\right)e^{-\lambda\varphi}}$$

& others

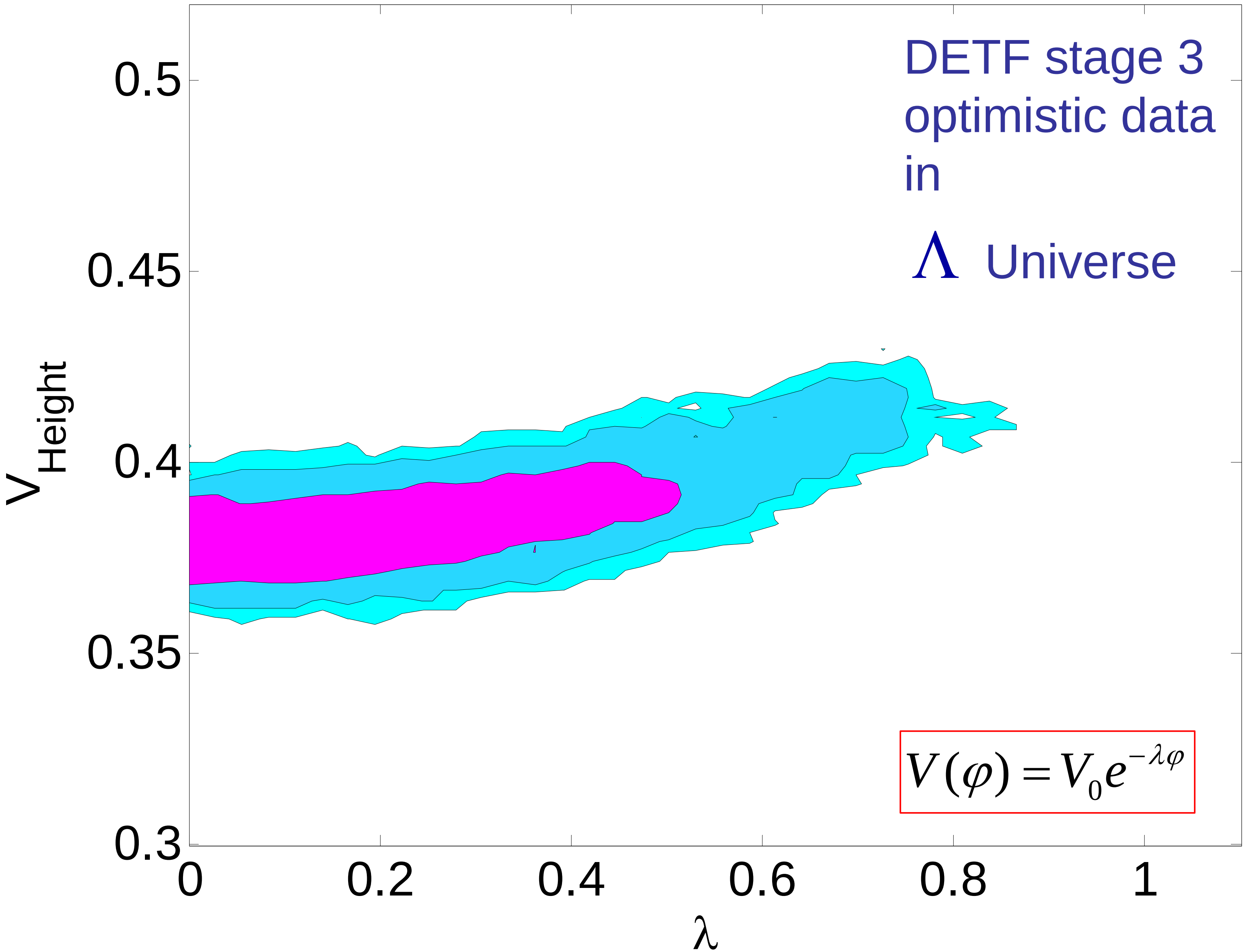
Challenges: Potential parameters can have very complicated relationships to cosmic observables

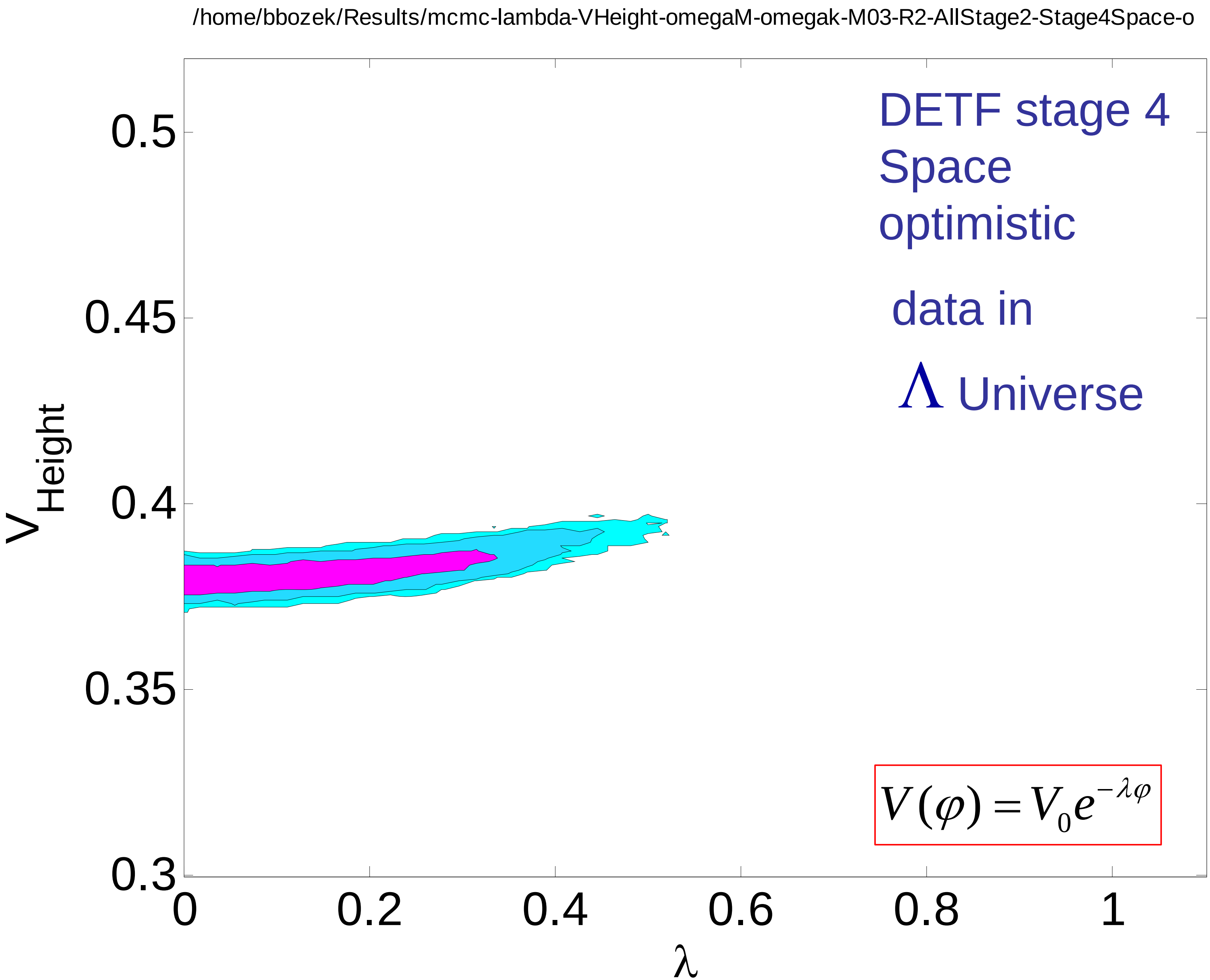
Resolved with good parameter choices (functional form and value range)

Sneak preview:

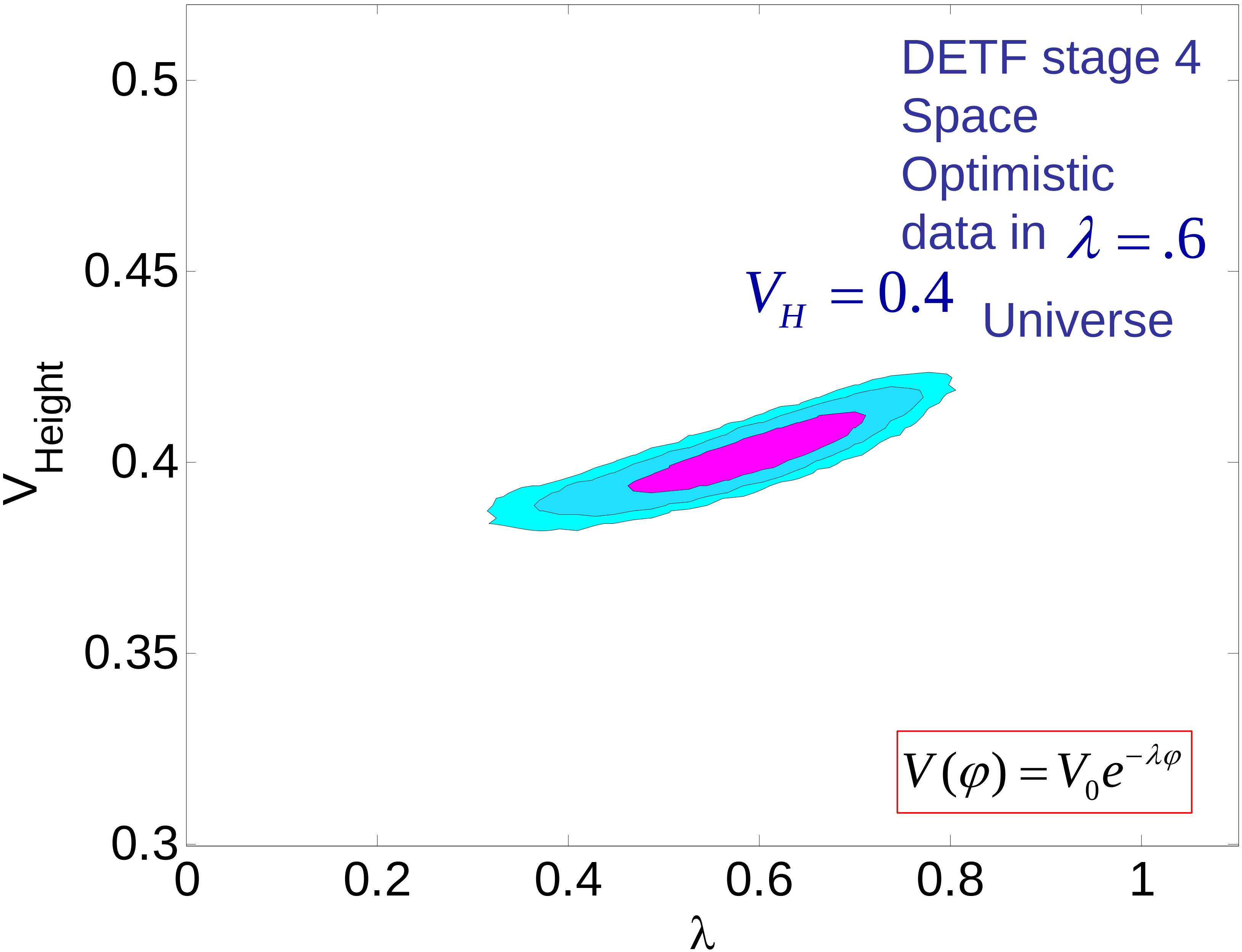

DETF stage 2
data in
Λ Universe
$V(\varphi) = V_0 e^{-\lambda\varphi}$
V_{Height}
0.5
0.45
0.4
0.35
0.3
0.2
0.4
0.6
0.8
1
λ

/home/bbozek/Results/mcmc-lambda-VHeight-omegaM-omegak-M03-R1-AllStage2-AllStage3p-o




/home/bbozek/Results/mcmc-lambda-VHeight-omegaM-omegak-M03-R2-AllStage2-Stage4Space-o
DETF stage 4
Space
optimistic
data in
Λ Universe
$V(\varphi) = V_0 e^{-\lambda\varphi}$
V_{Height}
λ
0.5
0.45
0.4
0.35
0.3
0
0.2
0.4
0.6
0.8
1

/home/bbozek/ResultsLambda_6/mcmc-Vo-lambda-VHeight-omegaM-omegak-M03-R2-AllStage2-Stage4Space-o



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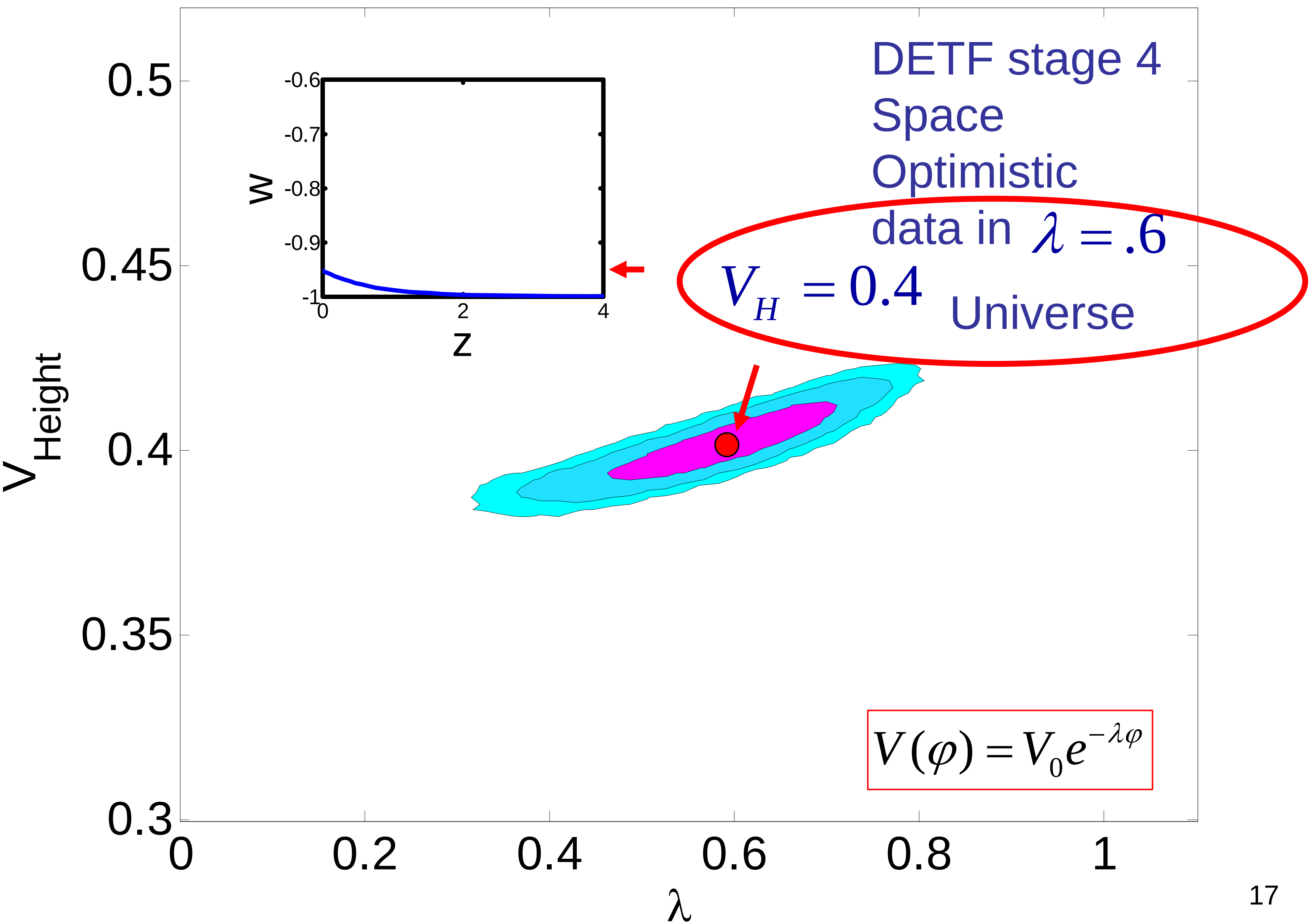

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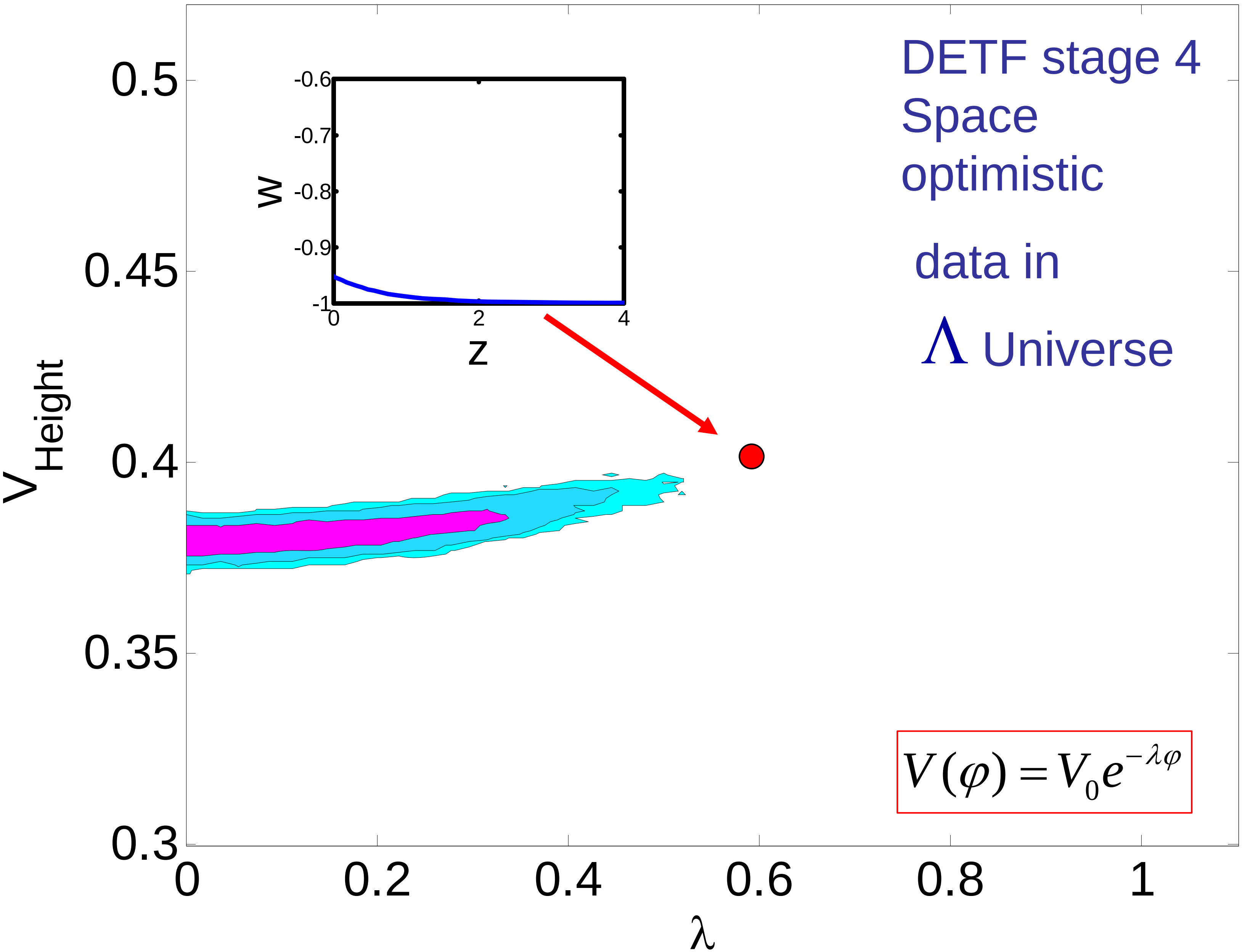

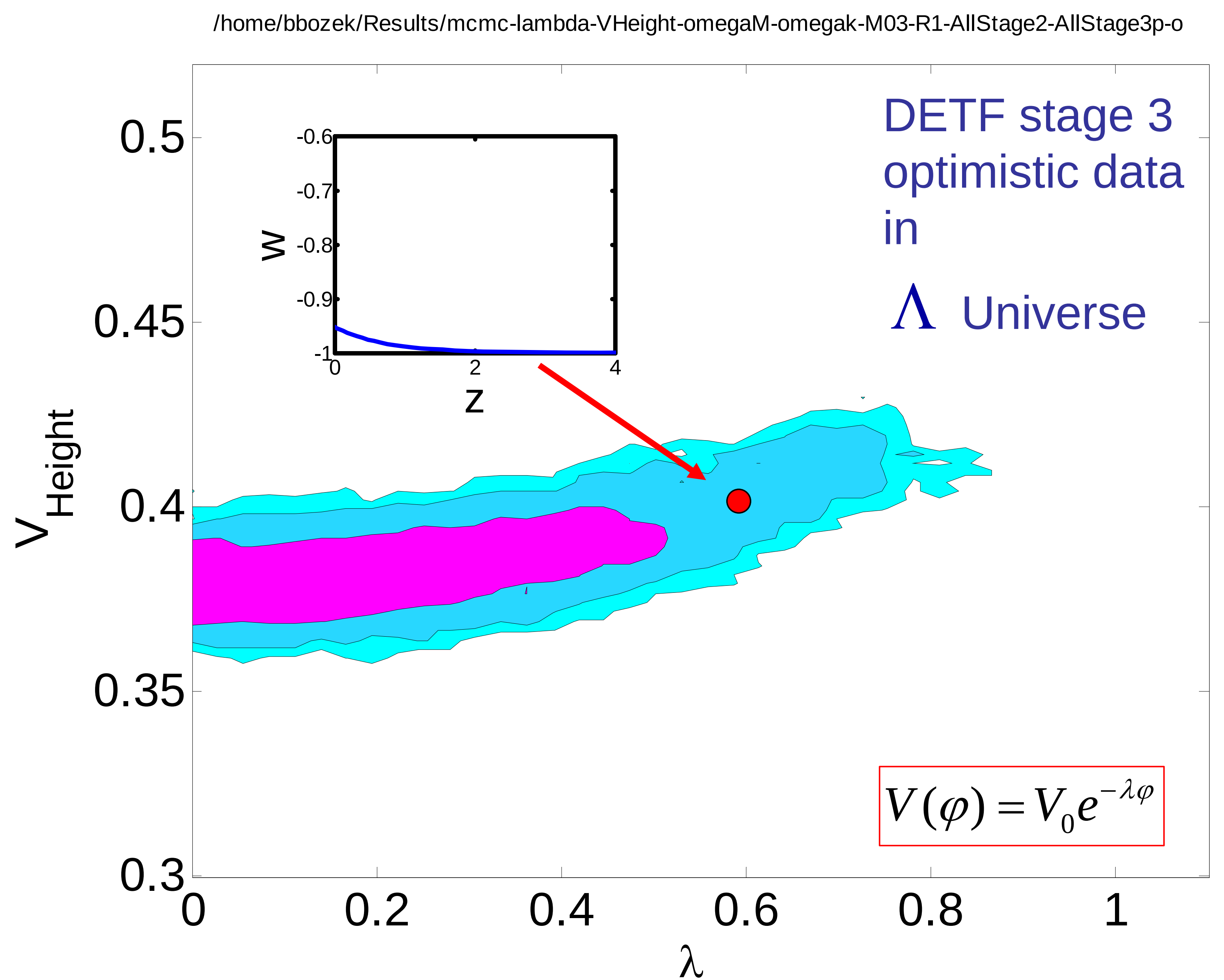
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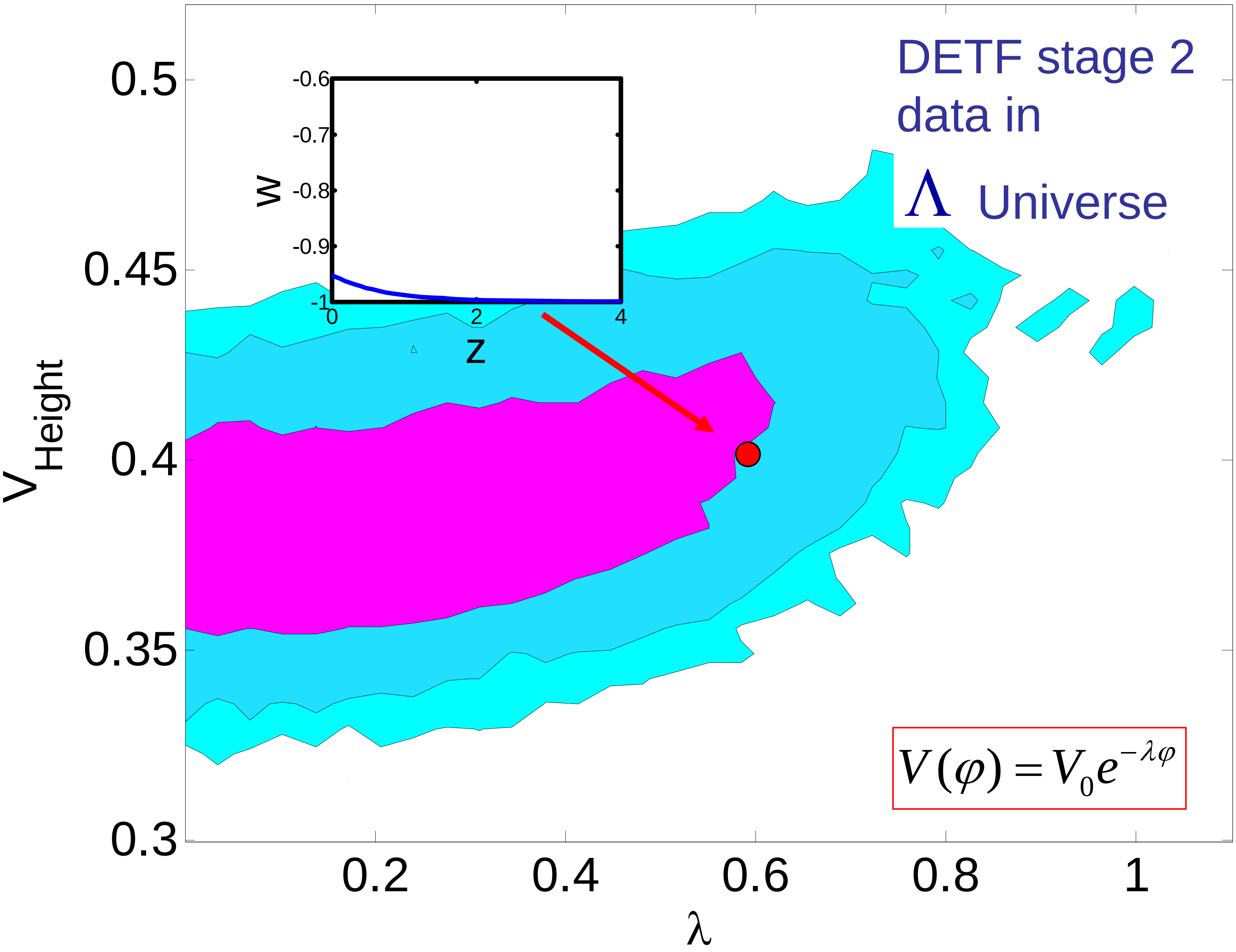
DETF stage 3
optimistic data
in
Λ Universe
$V(\varphi) = V_0 e^{-\lambda\varphi}$
V_{Height}
λ
0.5
0.45
0.4
0.35
0.3
0
0.2
0.4
0.6
0.8
1
w
z
-0.6
-0.7
-0.8
-0.9
-1
0
2
4


DETF stage 2
data in
Λ Universe
$V(\varphi) = V_0 e^{-\lambda\varphi}$
w
z
-0.6
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-0.9
-1
0
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V_{Height}
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0.5
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1

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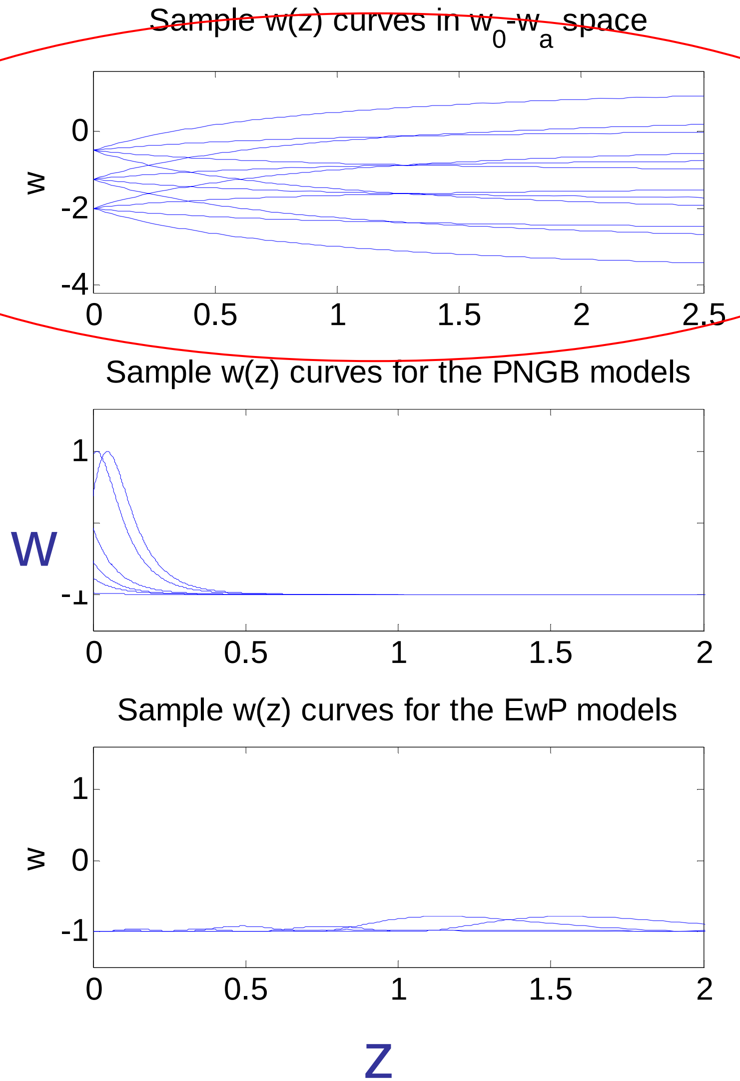
How good is the w(a) ansatz?



$$w(a) = w_0 + w_a(1-a)$$

w0-wa can only do these

DE models can do this
(and much more)

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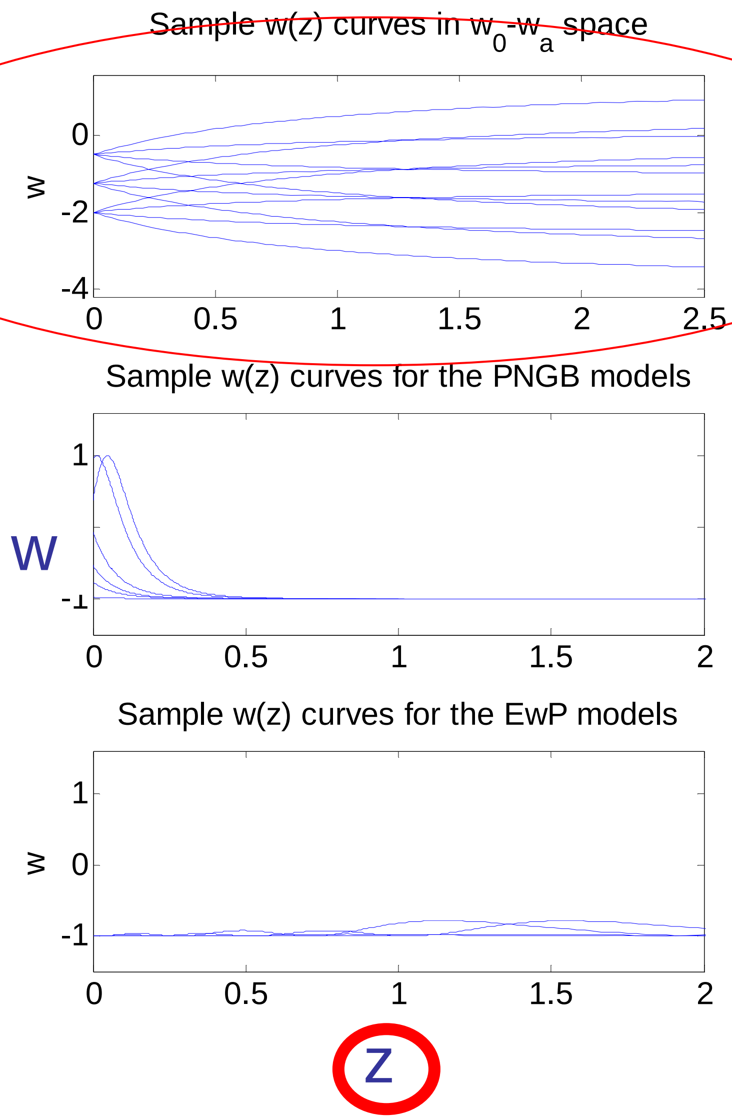

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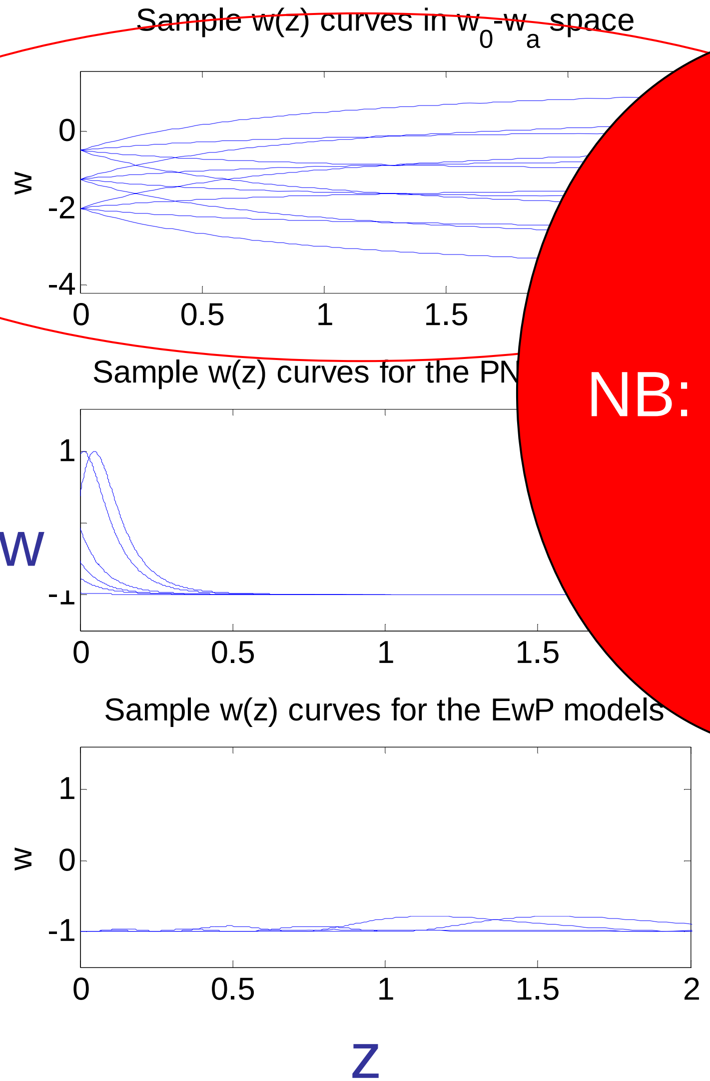


NB: Better than

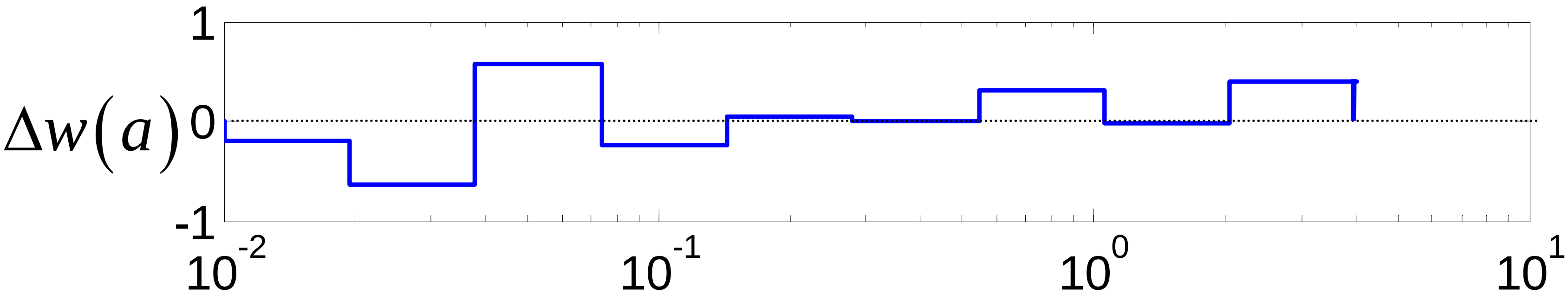
$$w(a) = w_0 + w_a(1-a)$$

va can only do these

$$w(a) = w_0$$

DE models can do this
(and much more)

Try 9D stepwise constant w(a)



$$\boxed{w(a) = -1 + +\Delta w(a) = -1 + \sum_{i=1}^{9} w_i T(a_i, a_{i+1})}$$

9 parameters are coefficients of the "top hat functions" $T(a_i, a_{i+1})$

AA & G Bernstein 2006 (astro-ph/0608269). More detailed info can be found at http://www.physics.ucdavis.edu/Cosmology/albrecht/MI0608269/

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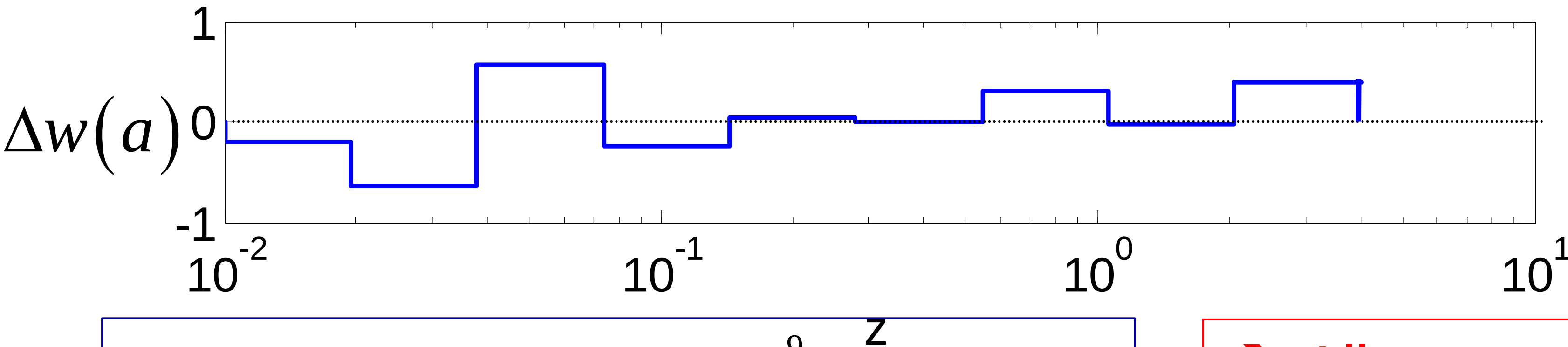

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➔ Allows each experiment to "put its best foot forward"

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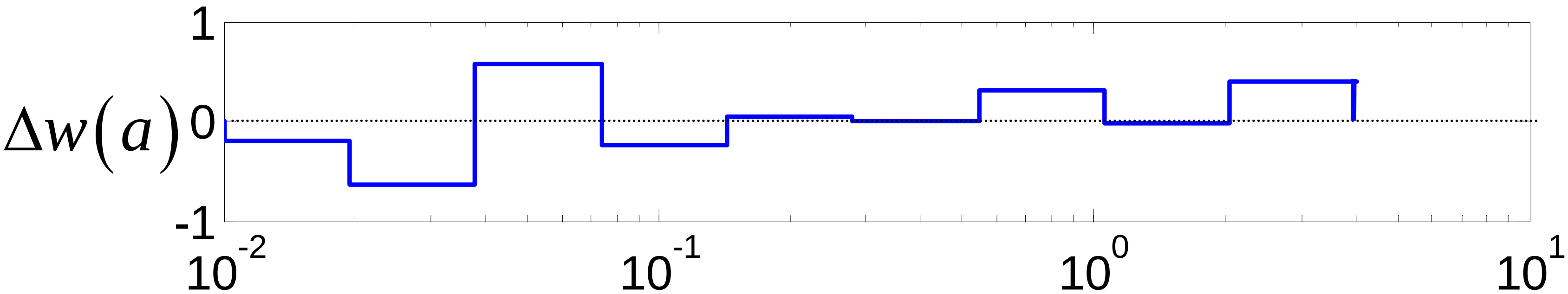

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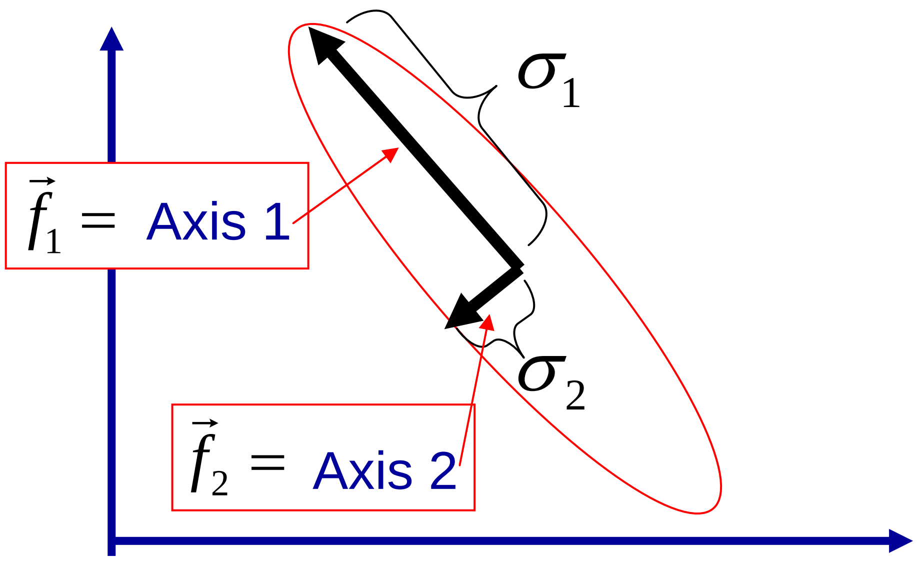
"Convergence"

AA & G Bernstein 2006

Q: How do you describe error ellipsis in 9D space?

A: In terms of 9 principle axes $\vec{f}_i$ and corresponding 9 errors σ_i:

2D illustration:



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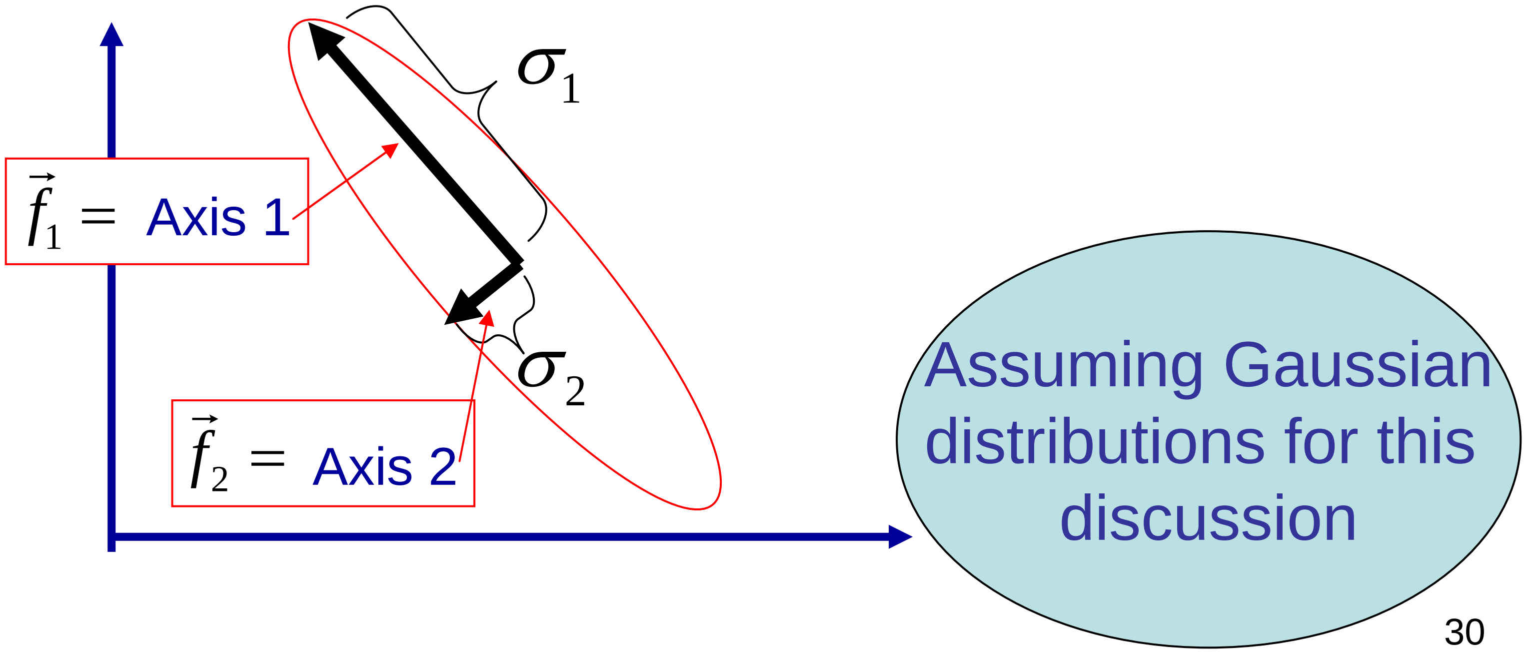

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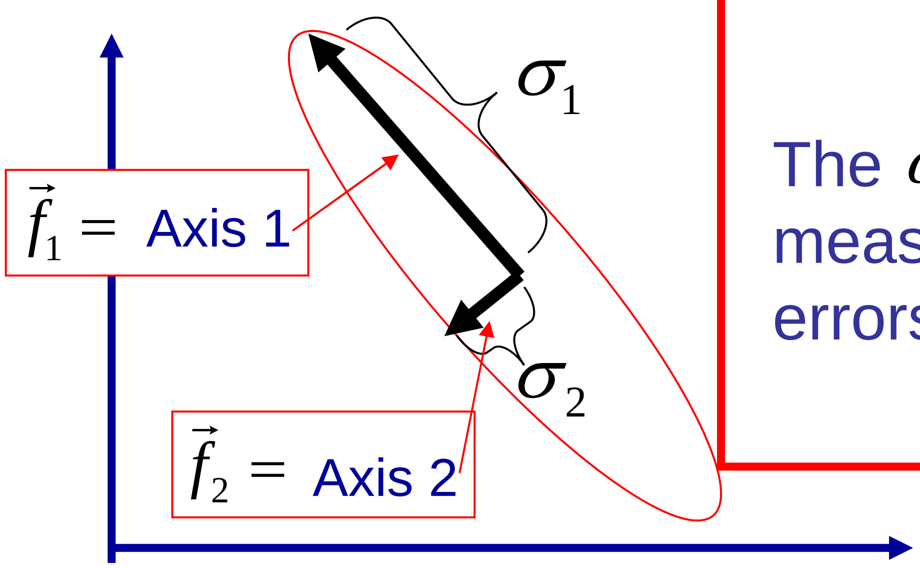


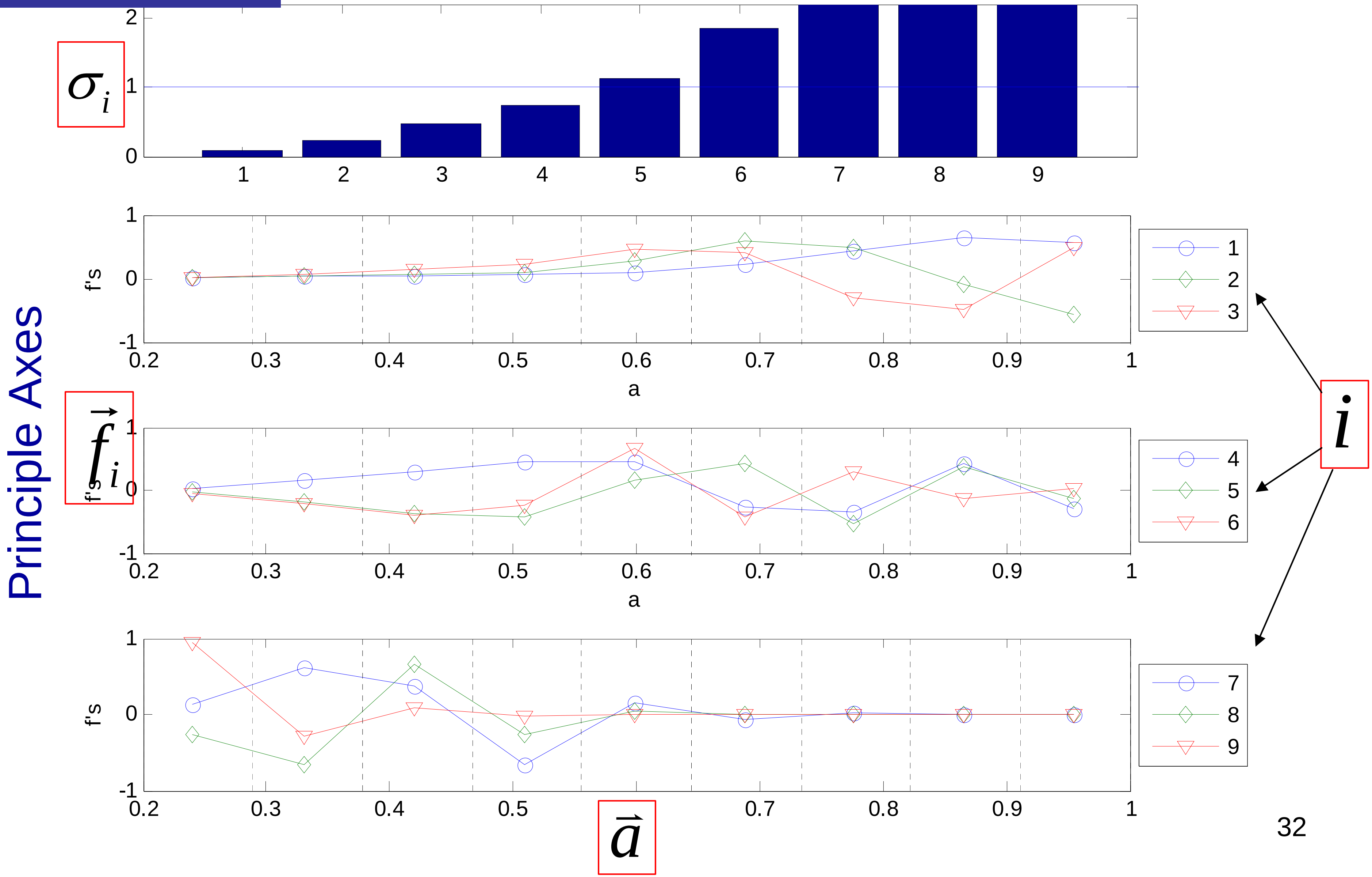
NB: in general the $\vec{f}_i$s form a complete basis:

$$\vec{w} = \sum_i \alpha_i \vec{f}_i$$

The α_i are independently measured qualities with errors σ_i

Characterizing 9D ellipses by principle axes and corresponding errors

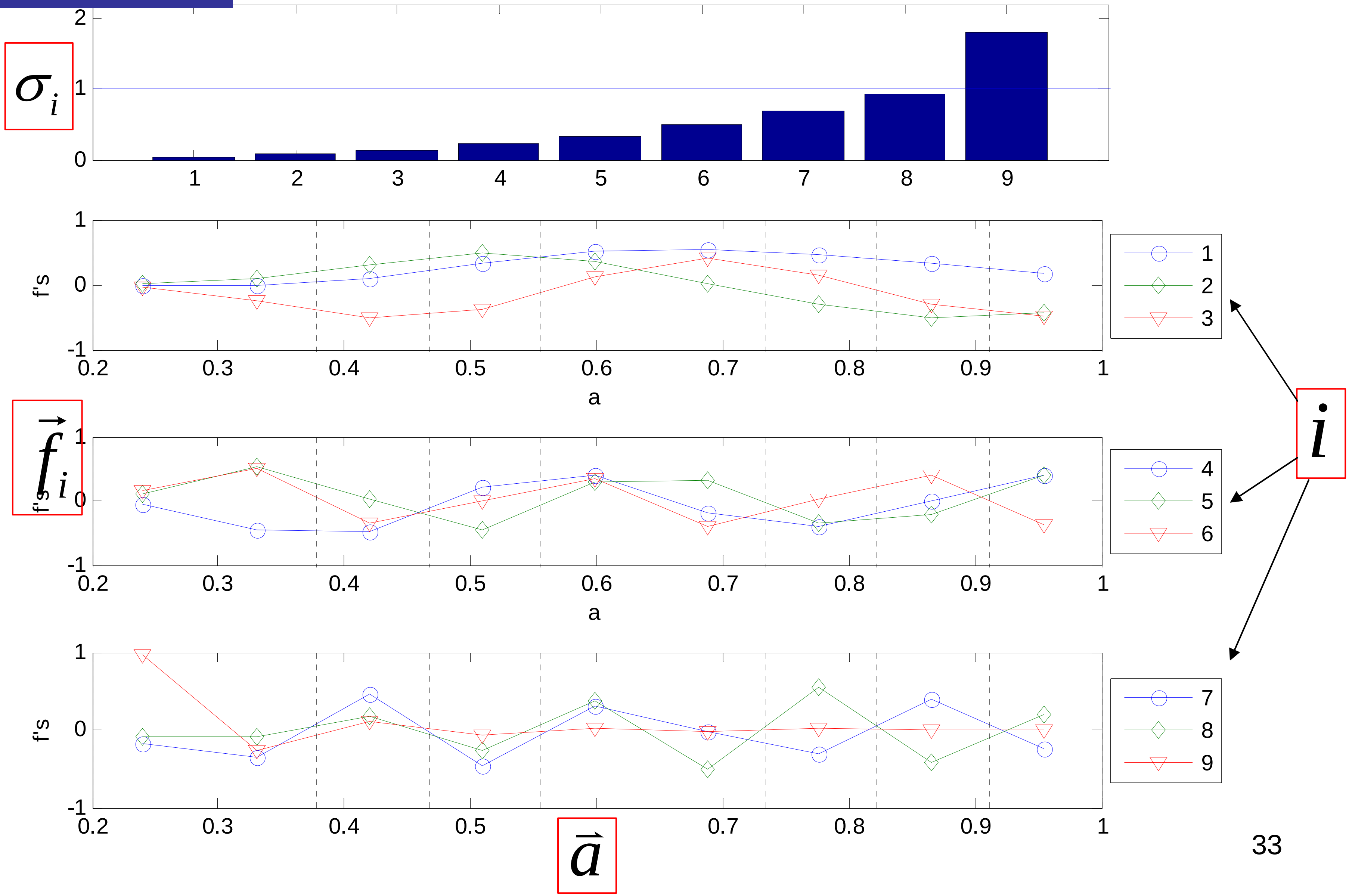
DETF stage 2



Characterizing 9D ellipses by principle axes and corresponding errors

WL Stage 4 Opt

Principle Axes



Characterizing 9D ellipses by principle axes and corresponding errors

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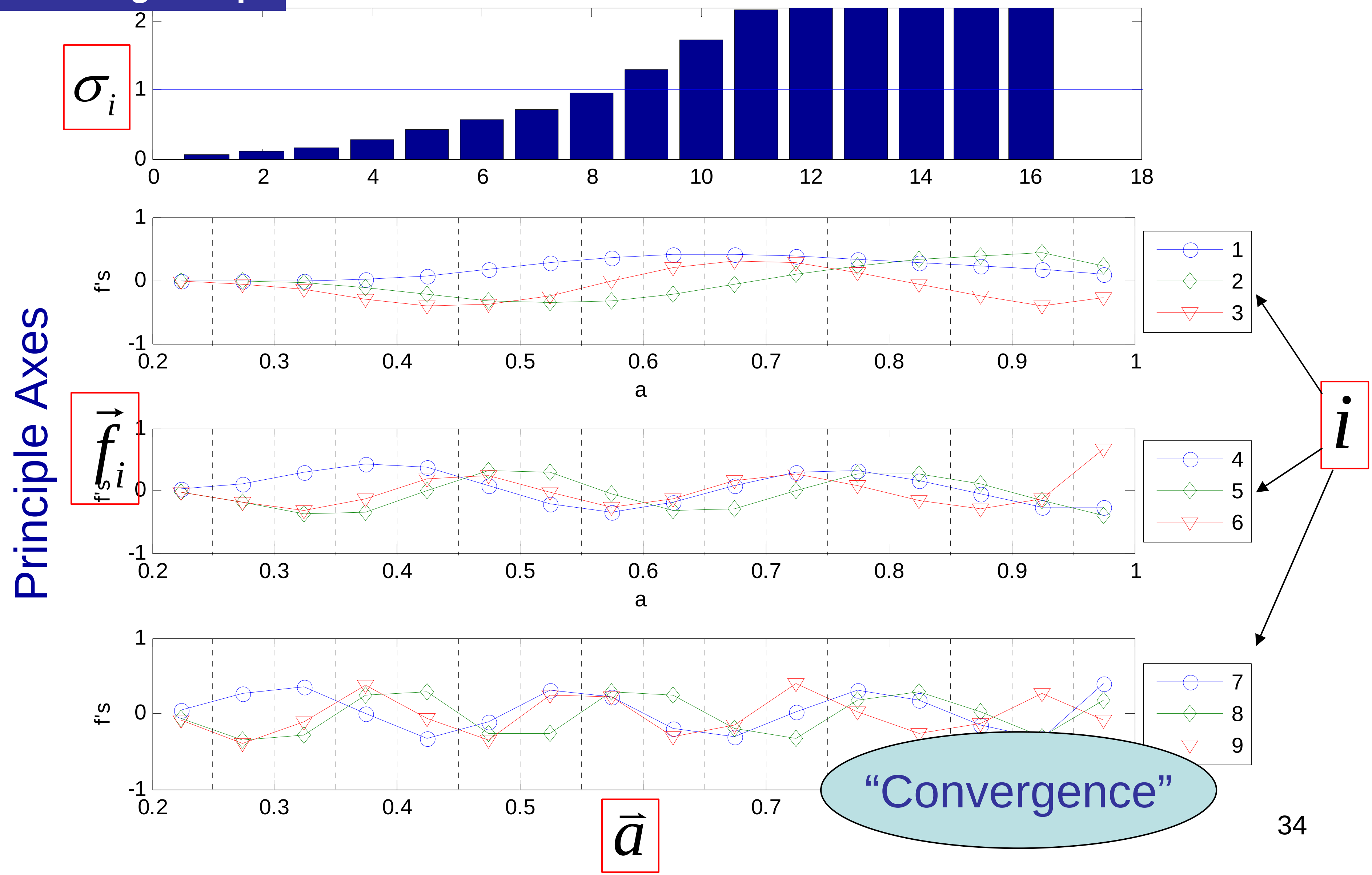


DETF Figure of Merit:

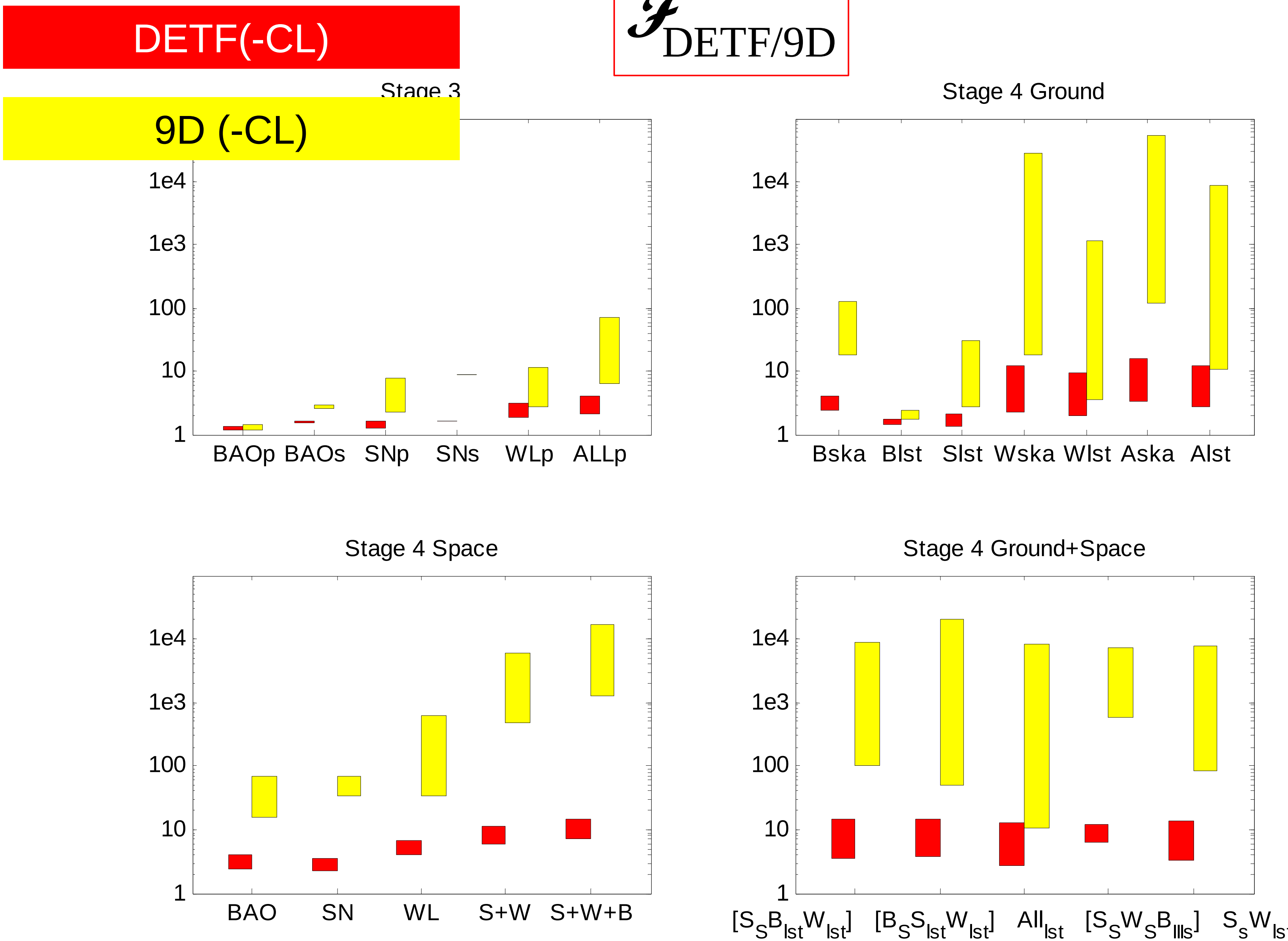
$$\boxed{\mathcal{F}_{\mathrm{DETF}} = \frac{1}{\sigma_1 \sigma_2}}$$

9D Figure of Merit:

$$\boxed{\mathcal{F}_{\mathrm{9D}} = \frac{1}{\prod_{i=1}^{9} \sigma_i}}$$

If $\sigma_i > 1$ we set $\sigma_i = 1$

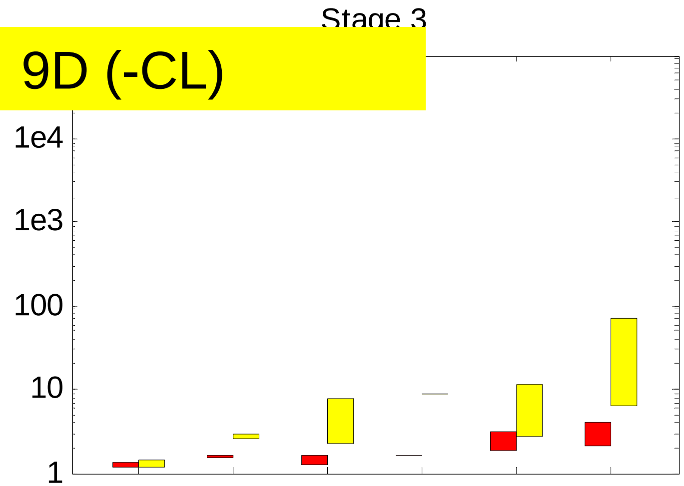
$\mathcal{F}_{\mathrm{DETF/9D}}$

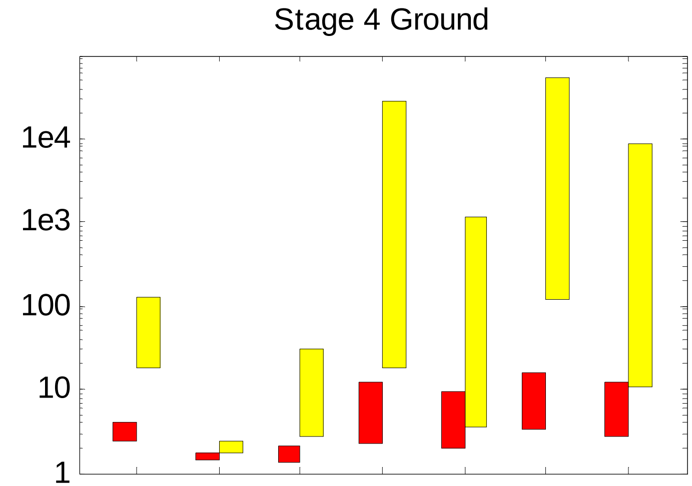


DETF(-CL)

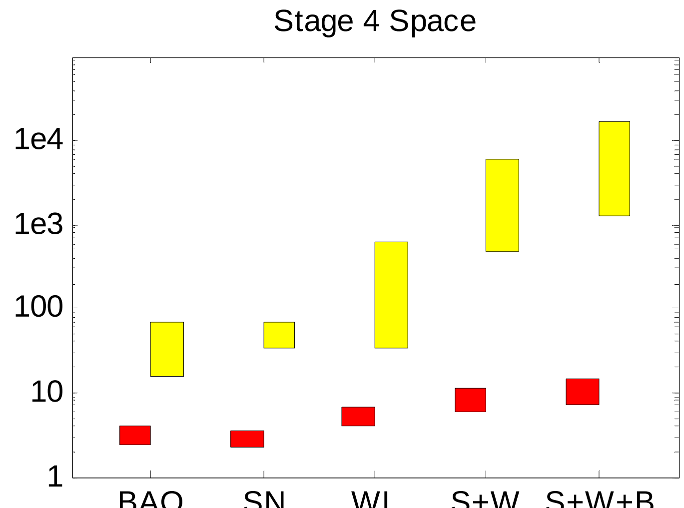
9D (-CL)

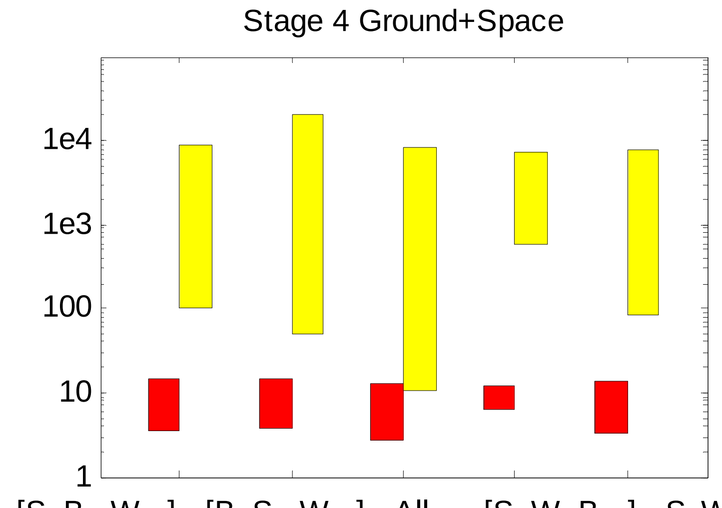
$\mathcal{F}_{\mathrm{DETF/9D}}$





Stage 2 ➔ Stage 3 = 1 order of magnitude (vs 0.5 for DETF)





Stage 2 ➔ Stage 4 = 3 orders of magnitude (vs 1 for DETF)

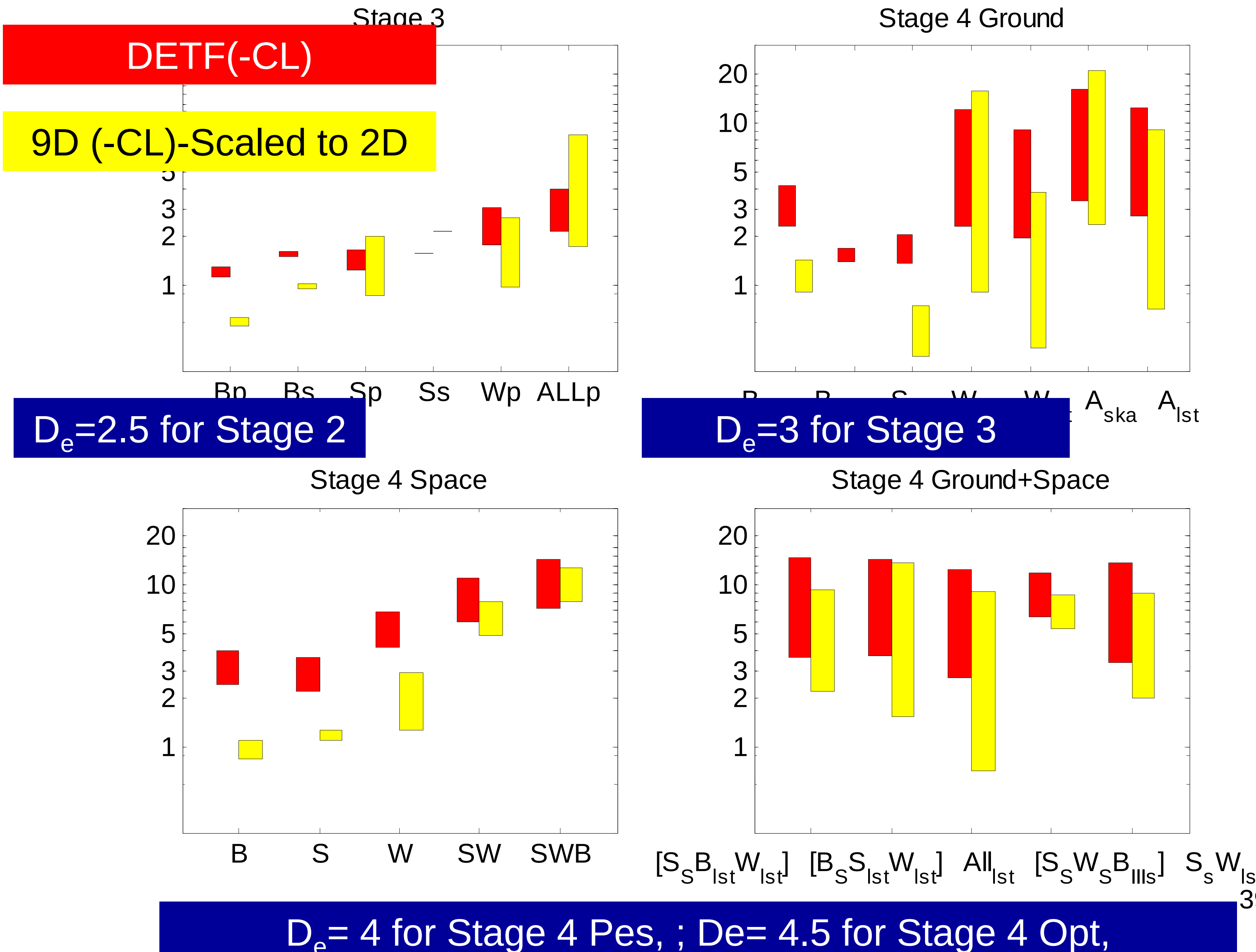
Define the “scale to 2D” function

$$\boxed{\mathcal{S}_{\mathrm{2D}}\left(\mathcal{F}\right) \equiv \mathcal{F}^{2/D_e}}$$

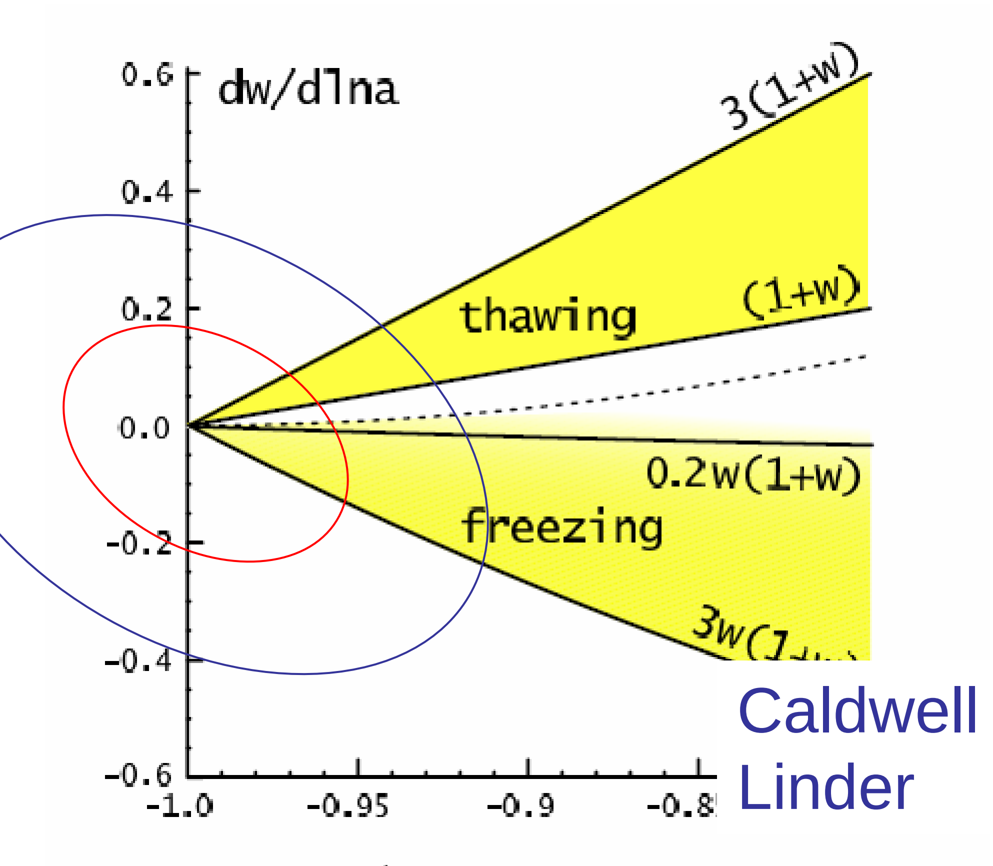
$$\mathcal{S}_{\mathrm{2D}}\left(\mathcal{F}\right) \equiv \frac{1}{\sigma_{ave}^{2}}$$

➔The idea: Construct an effective 2D FoM by assuming two dimensions with “average” errors (~geometric mean of 9D errors)

➔ Purpose: Separate out the impact of higher dimensions on comparisons with DETF, vs other information from the D9 space (such relative comparisons of data model).

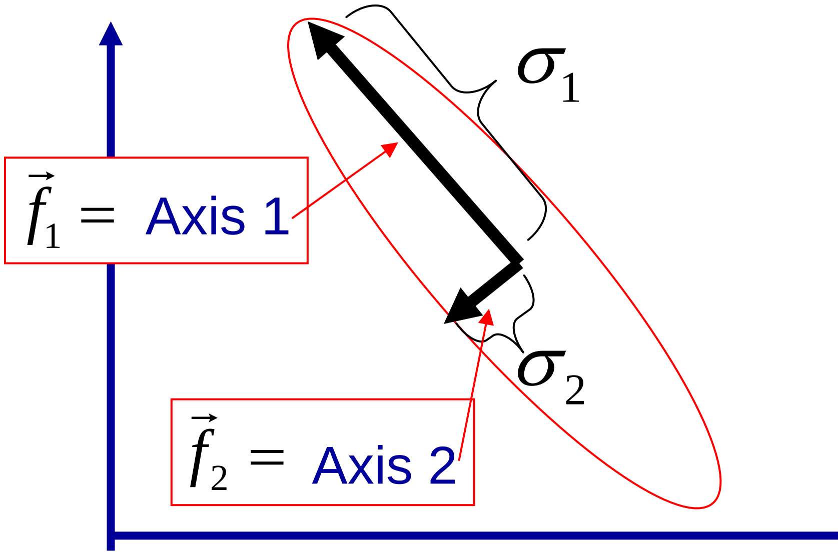

Stage 3
DETF(-CL)
9D (-CL)-Scaled to 2D
1
2
3
Bp Bs Sp Ss Wp ALLp
De=2.5 for Stage 2
Stage 4 Ground
20
10
5
3
2
1
Aska Alst
De=3 for Stage 3
Stage 4 Space
20
10
5
3
2
1
B S W SW SWB
Stage 4 Ground+Space
20
10
5
3
2
1
[SSBlstWlst] [BSSlstWlst] Alllst [SSWSBIIIs] SsWlst
De= 4 for Stage 4 Pes, ; De= 4.5 for Stage 4 Opt,

Discussion of cost/benefit analysis should take place in higher dimensions (vs current standards)



Caldwell & Linder

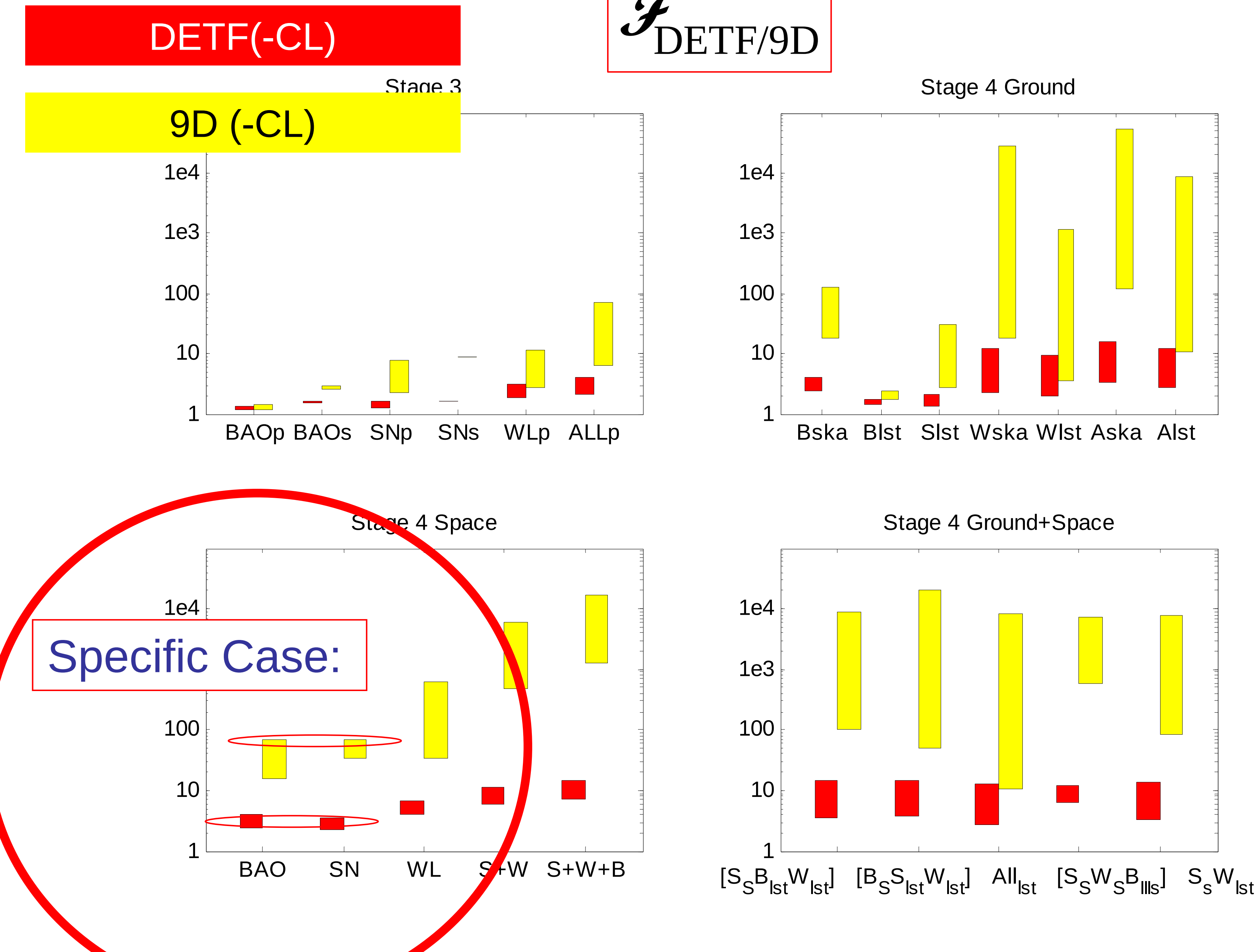
DETF



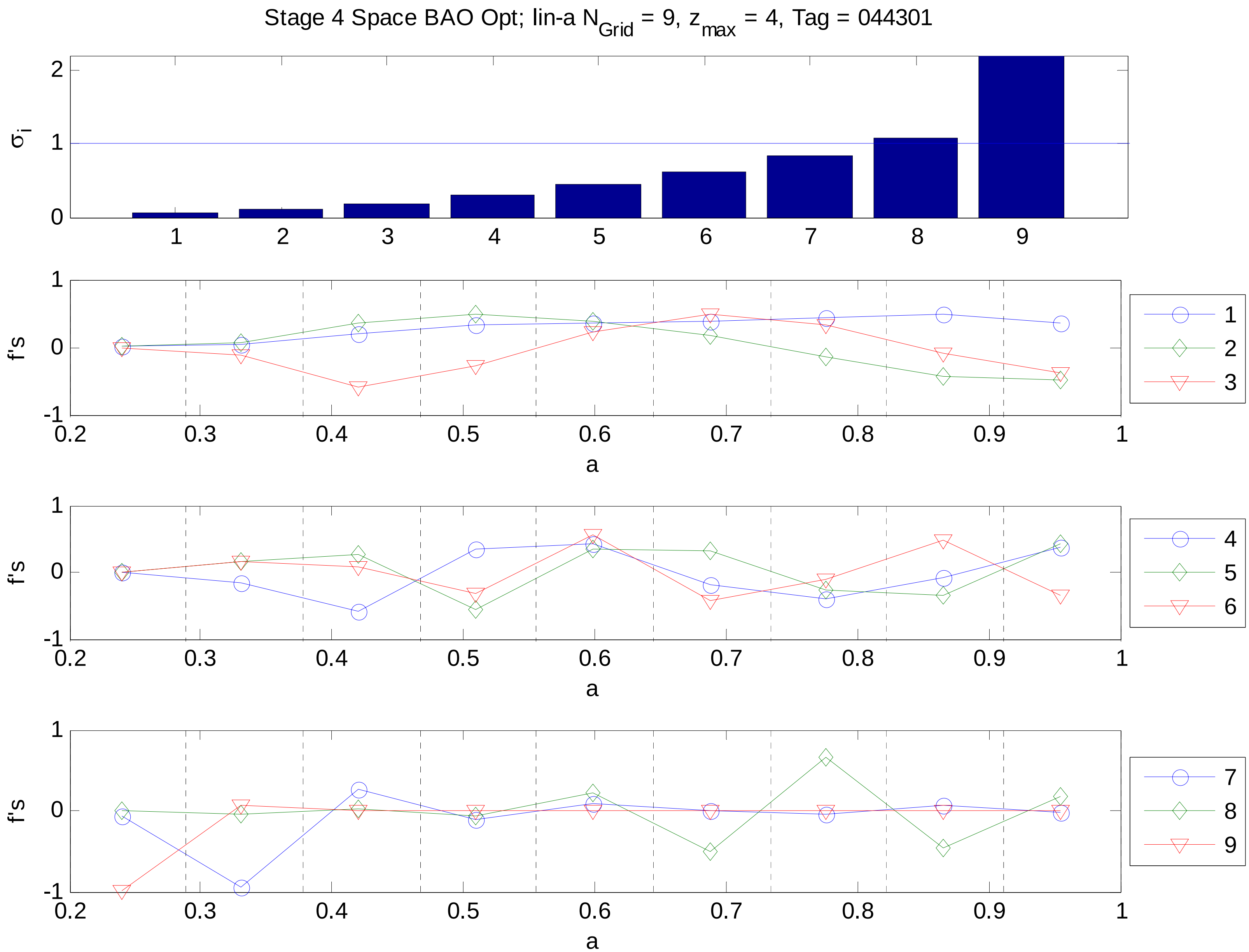
An example of the power of the principle component analysis:

Q: I’ve heard the claim that the DETF FoM is unfair to BAO, because w0-wa does not describe the high-z behavior which to which BAO is particularly sensitive. Why does this not show up in the 9D analysis?

$\mathcal{F}_{\mathrm{DETF/9D}}$

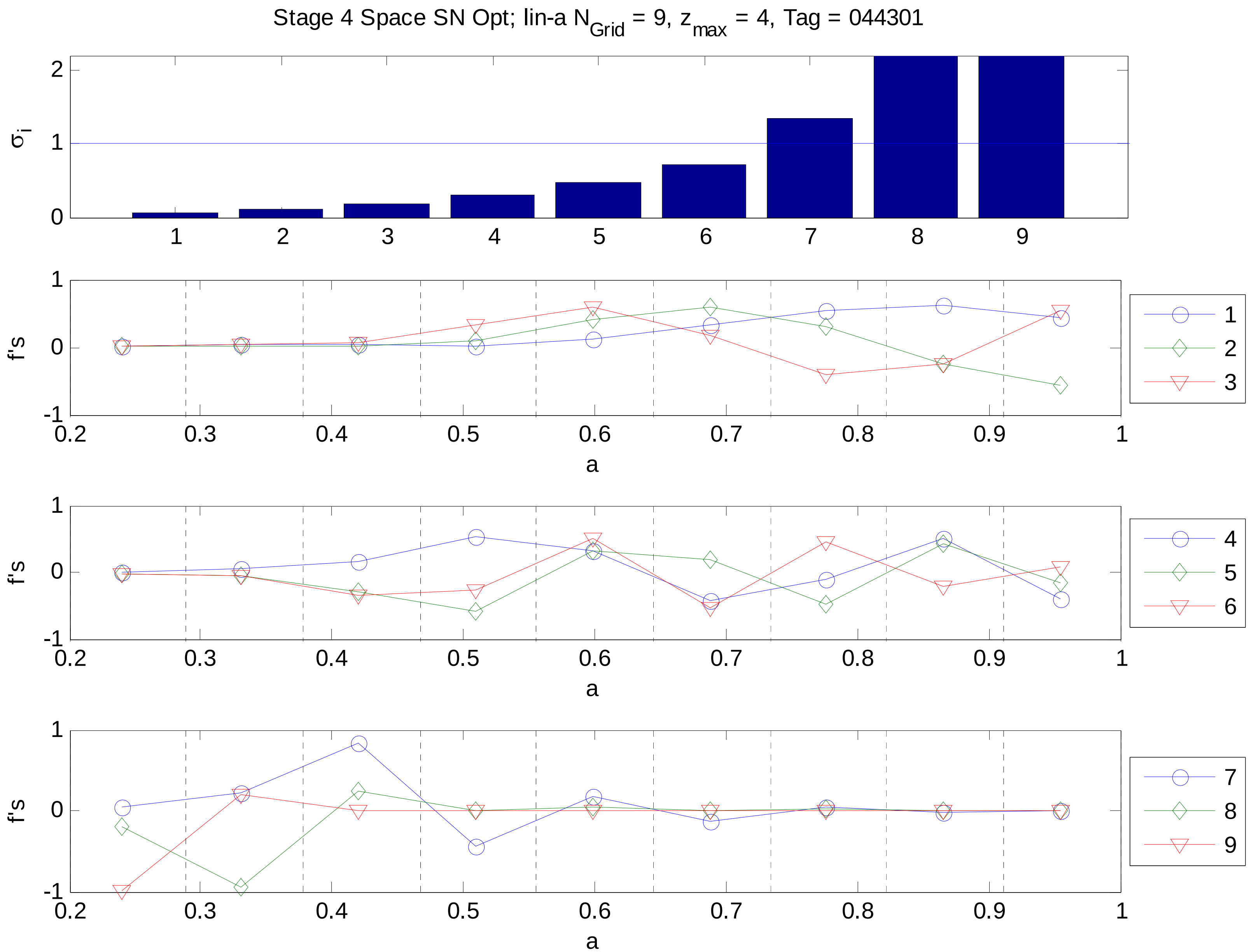


BAO



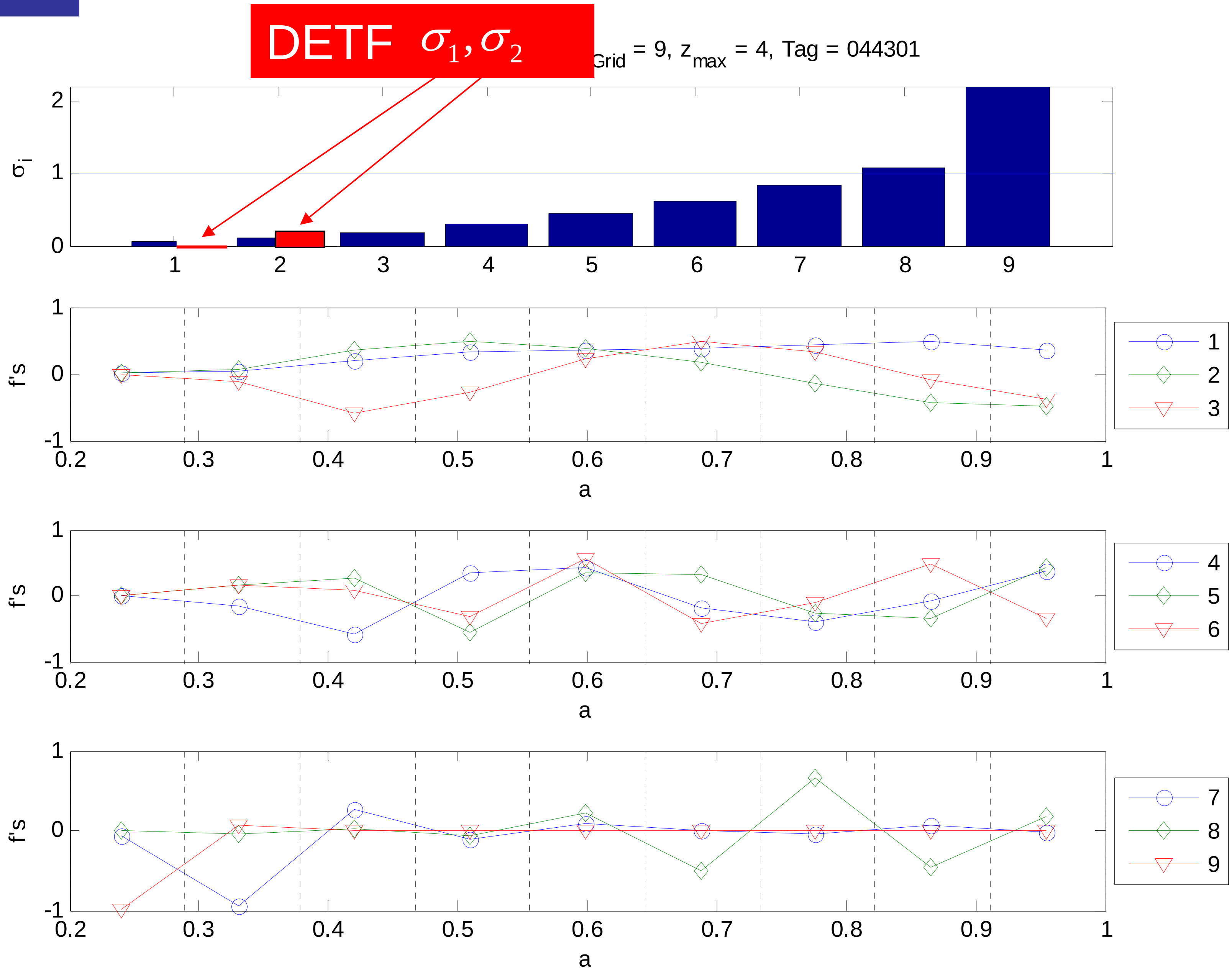
Stage 4 Space BAO Opt; lin-a N_{Grid} = 9, z_{max} = 4, Tag = 044301
σ_i
0
1
2
1 2 3 4 5 6 7 8 9
f's
1
0
-1
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
a
1
2
3
4
5
6
7
8
9

SN



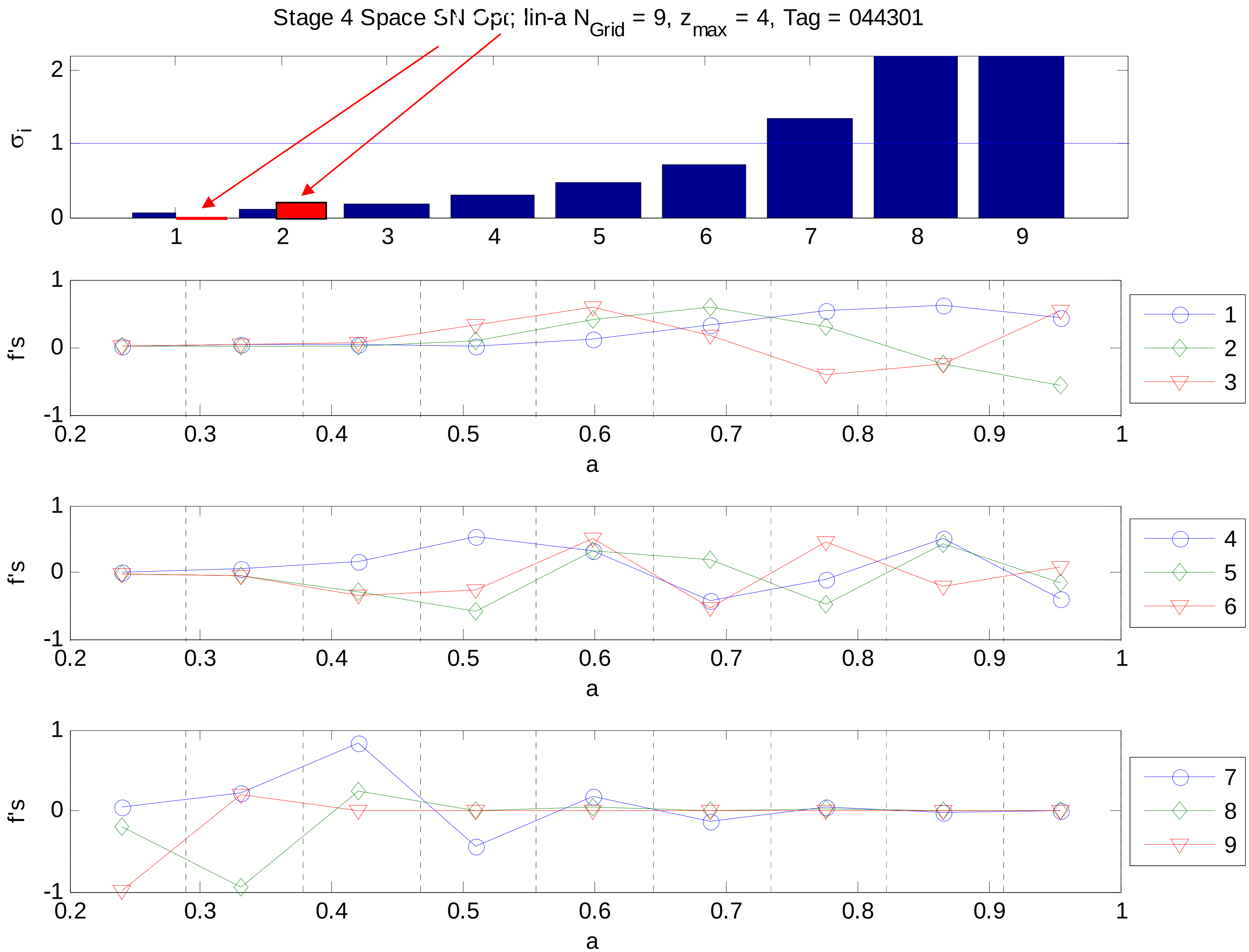
Stage 4 Space SN Opt; lin-a N_{Grid} = 9, z_{max} = 4, Tag = 044301
σ_i
f's
a
1
2
3
4
5
6
7
8
9

BAO



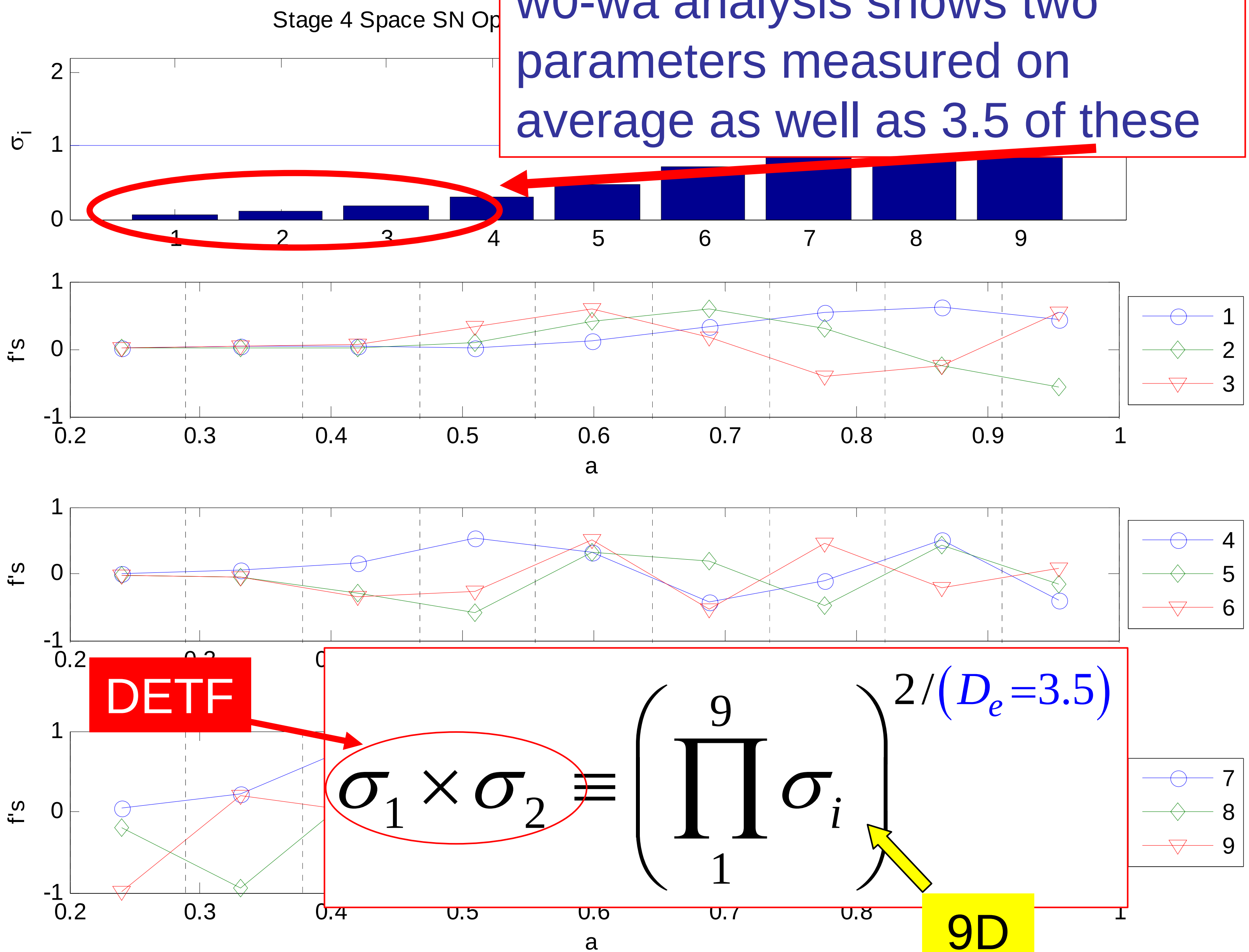
DETF σ_1, σ_2
Grid = 9, z_{max} = 4, Tag = 044301
σ_i
f's
a
1
2
3
4
5
6
7
8
9

SN



SN

w0-wa analysis shows two parameters measured on average as well as 3.5 of these



DETF

$$\sigma_1 \times \sigma_2 \equiv \left(\prod_{1}^{9} \sigma_i \right)^{2/(D_e=3.5)}$$

9D

Quick and dirty check on the impact of future data on your DE model:

1) Choose a data model and generate $\vec{f}_i$'s

2) Choose representative functions w(a) for your model

3) Find α_i coefficients in $\vec{w} = \sum_i \alpha_i \vec{f}_i$

4) The σ_i tell you how well the α_i will be measured

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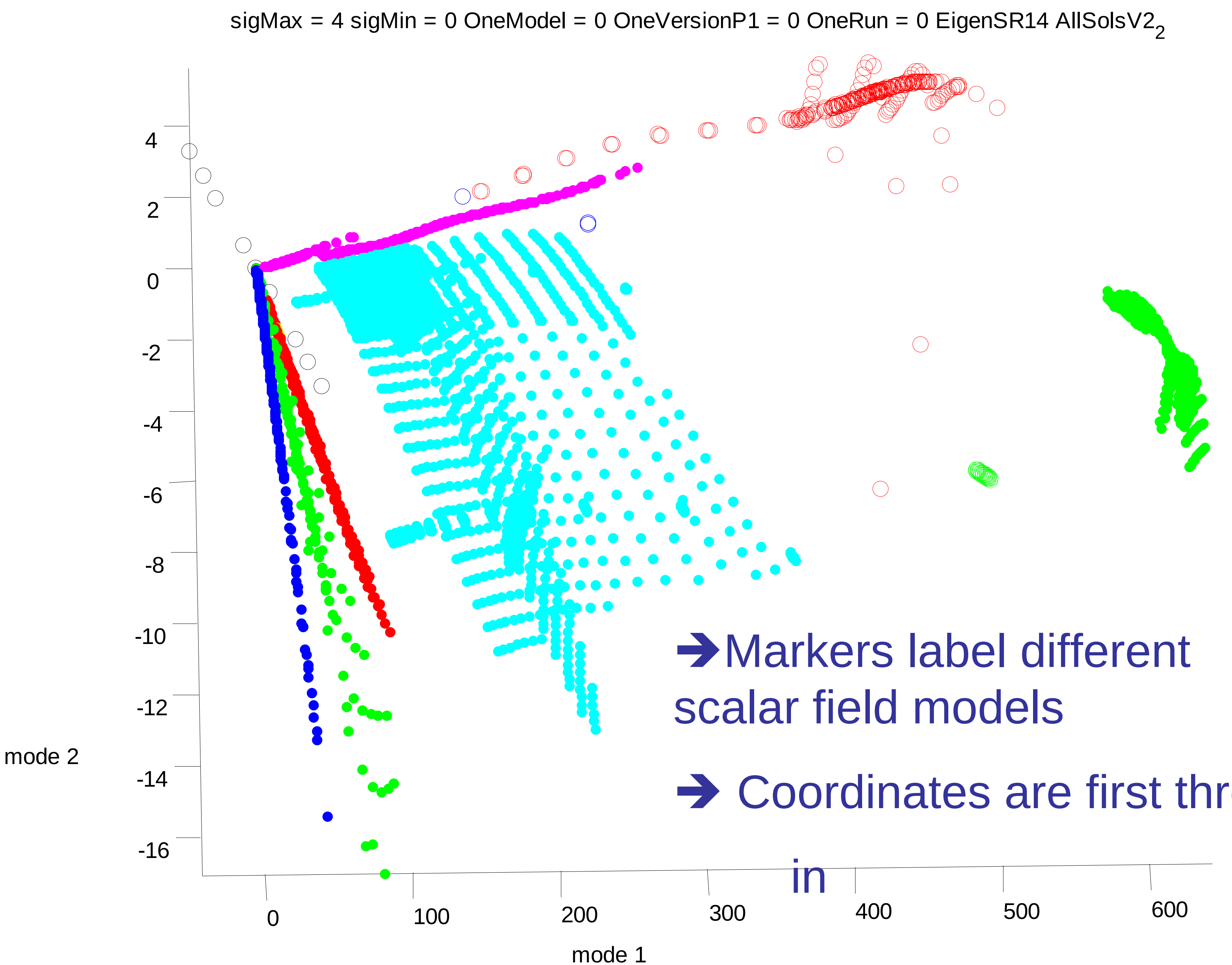
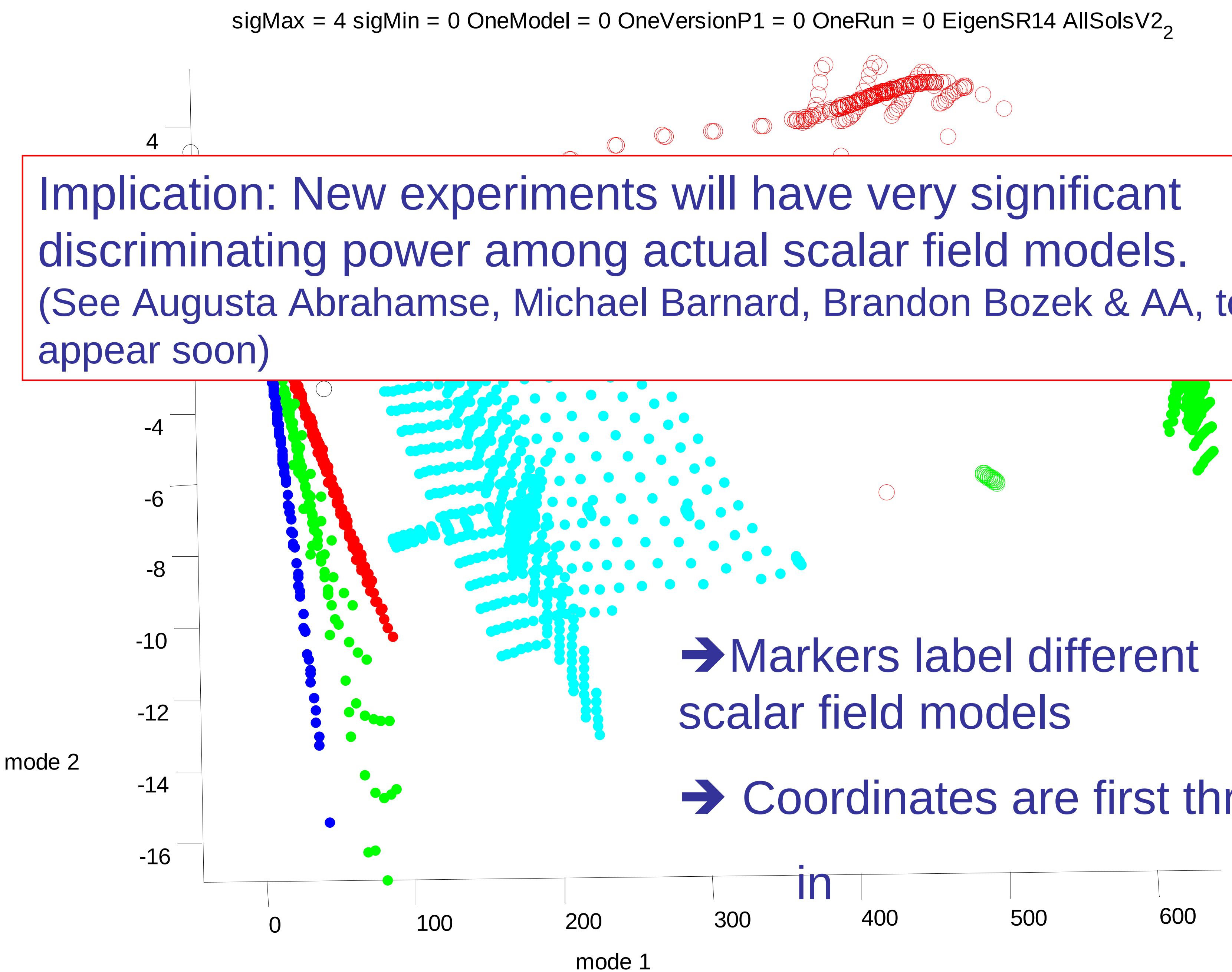
Or grab them from our web site



➔Markers label different scalar field models

➔ Coordinates are first three in



Implication: New experiments will have very significant discriminating power among actual scalar field models.
(See Augusta Abrahamse, Michael Barnard, Brandon Bozek & AA, to appear soon)

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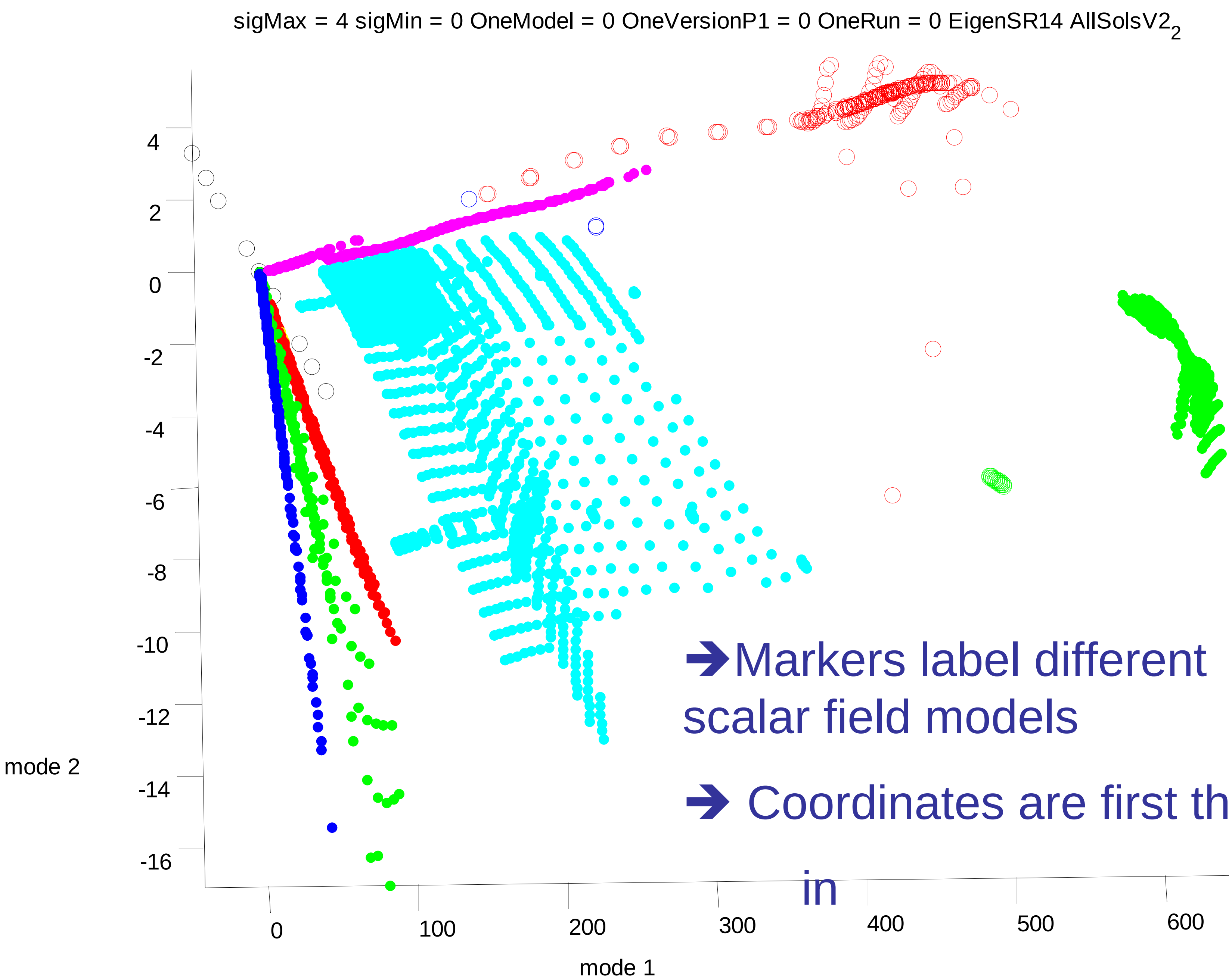
END

Extra material



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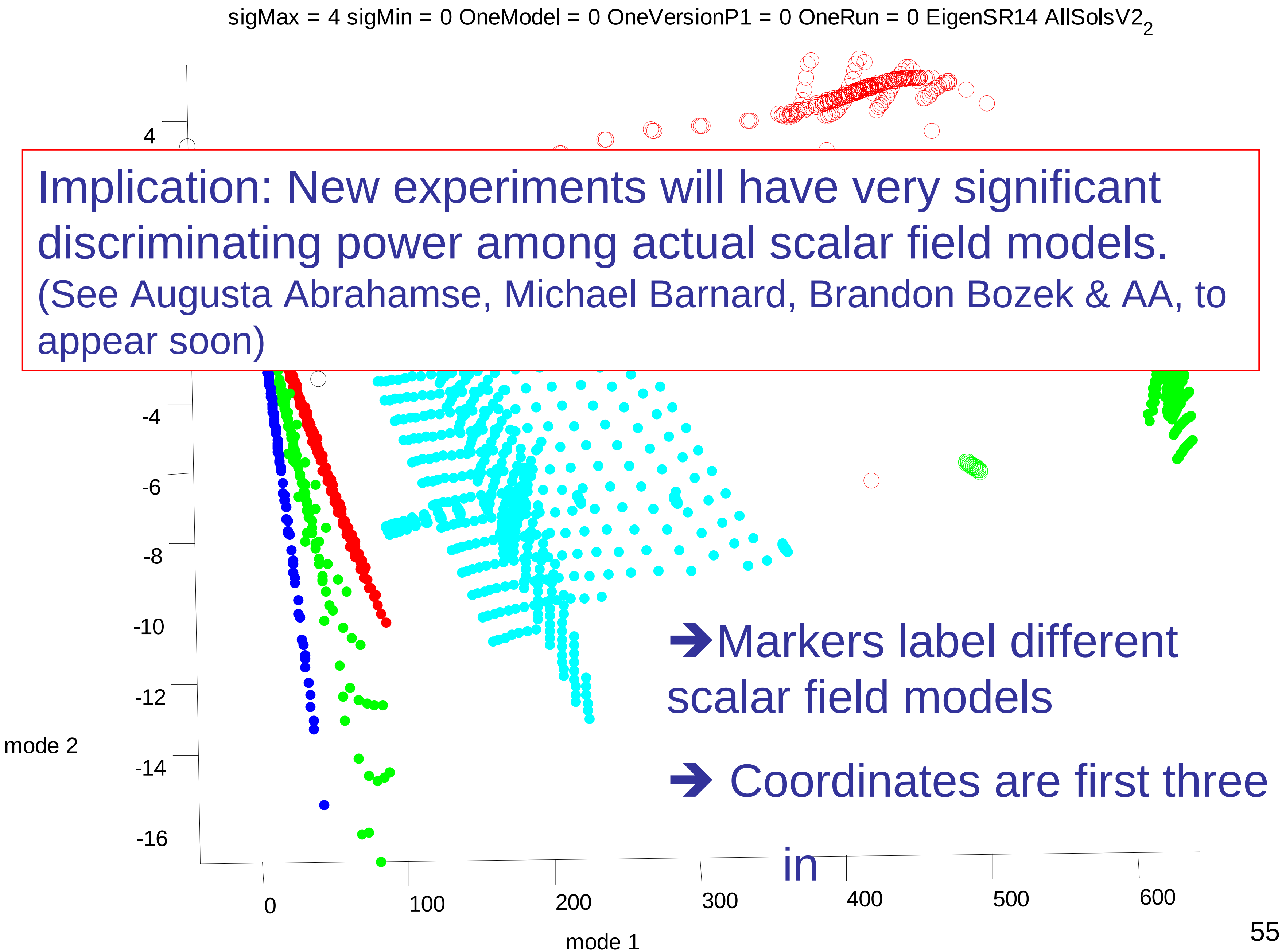

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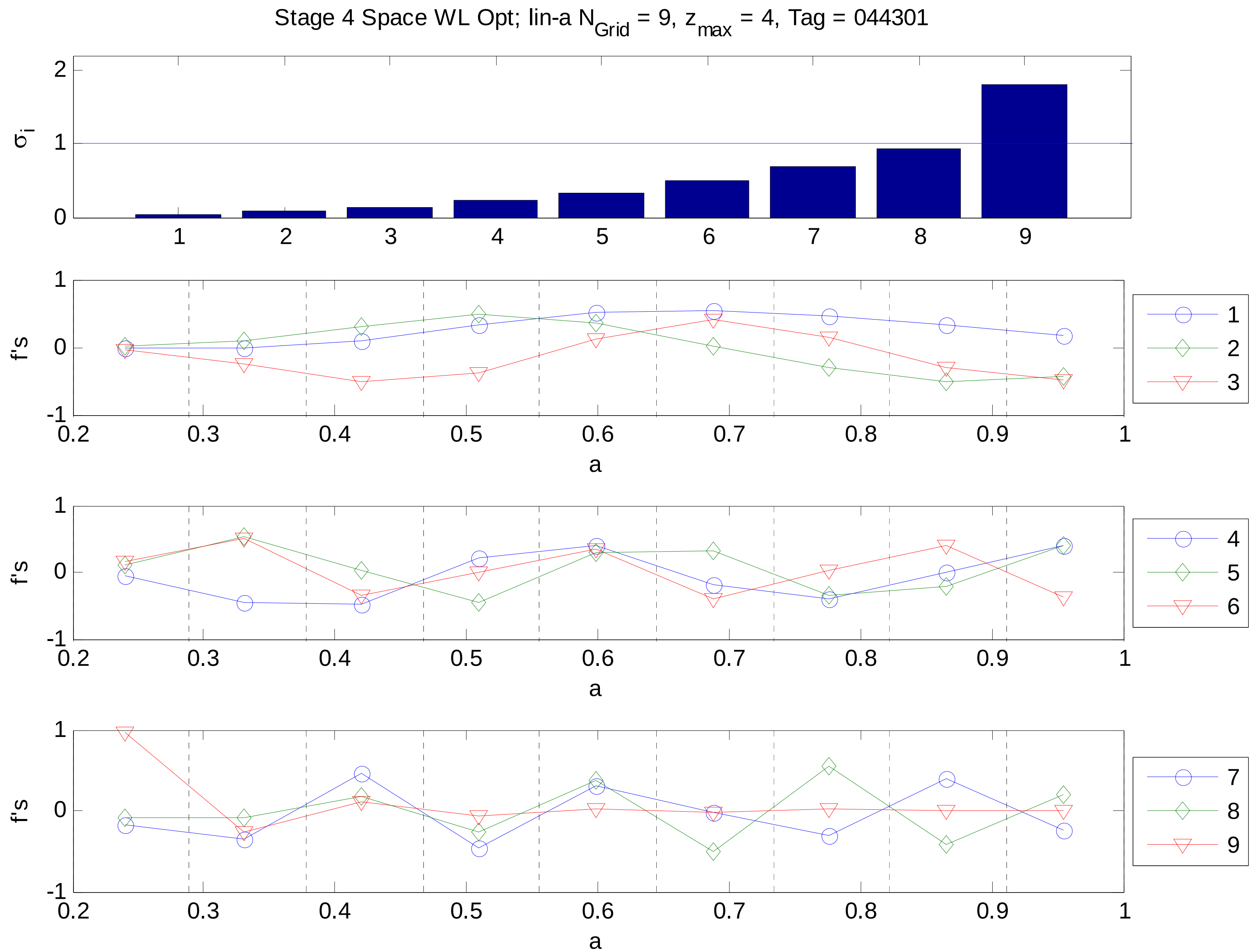
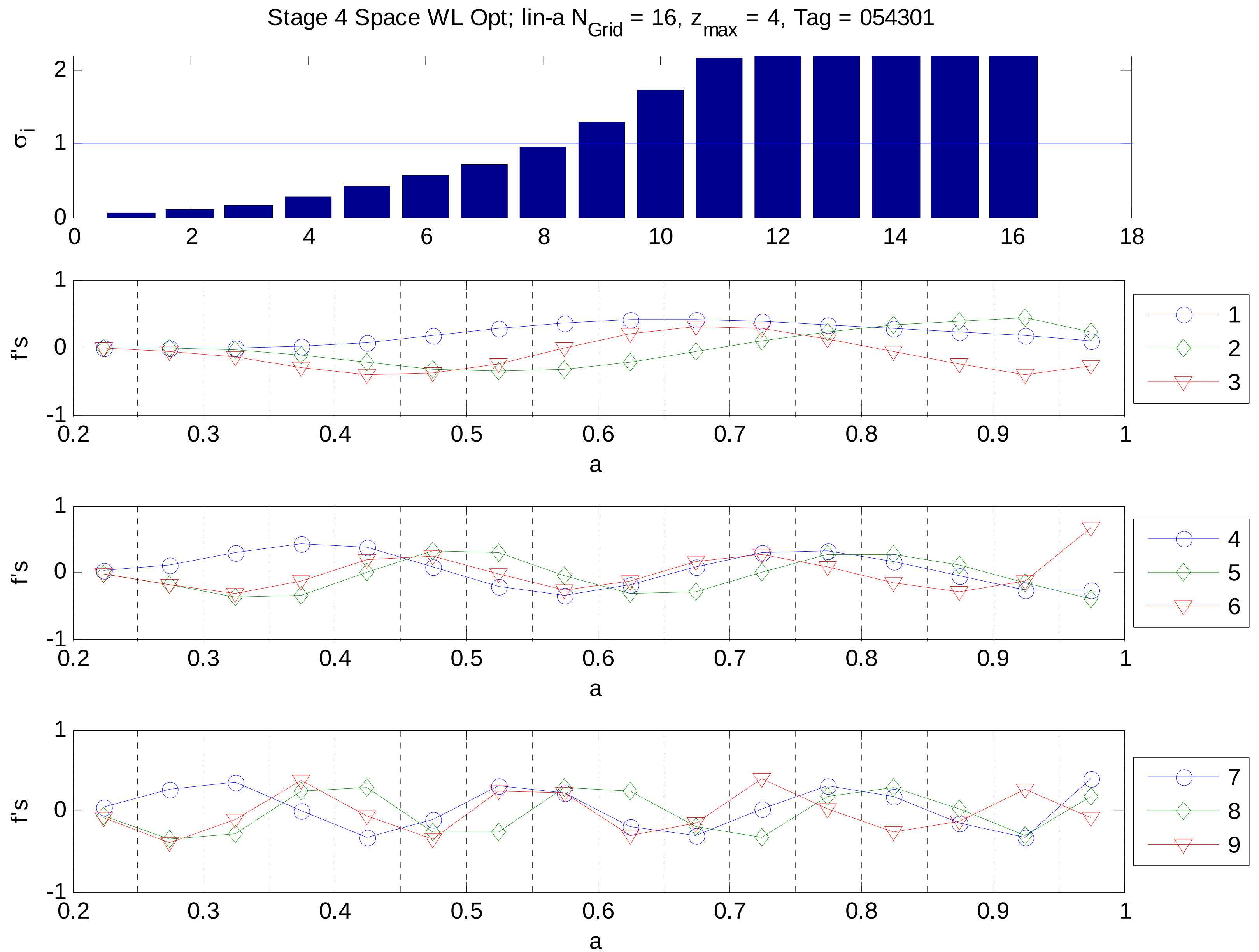
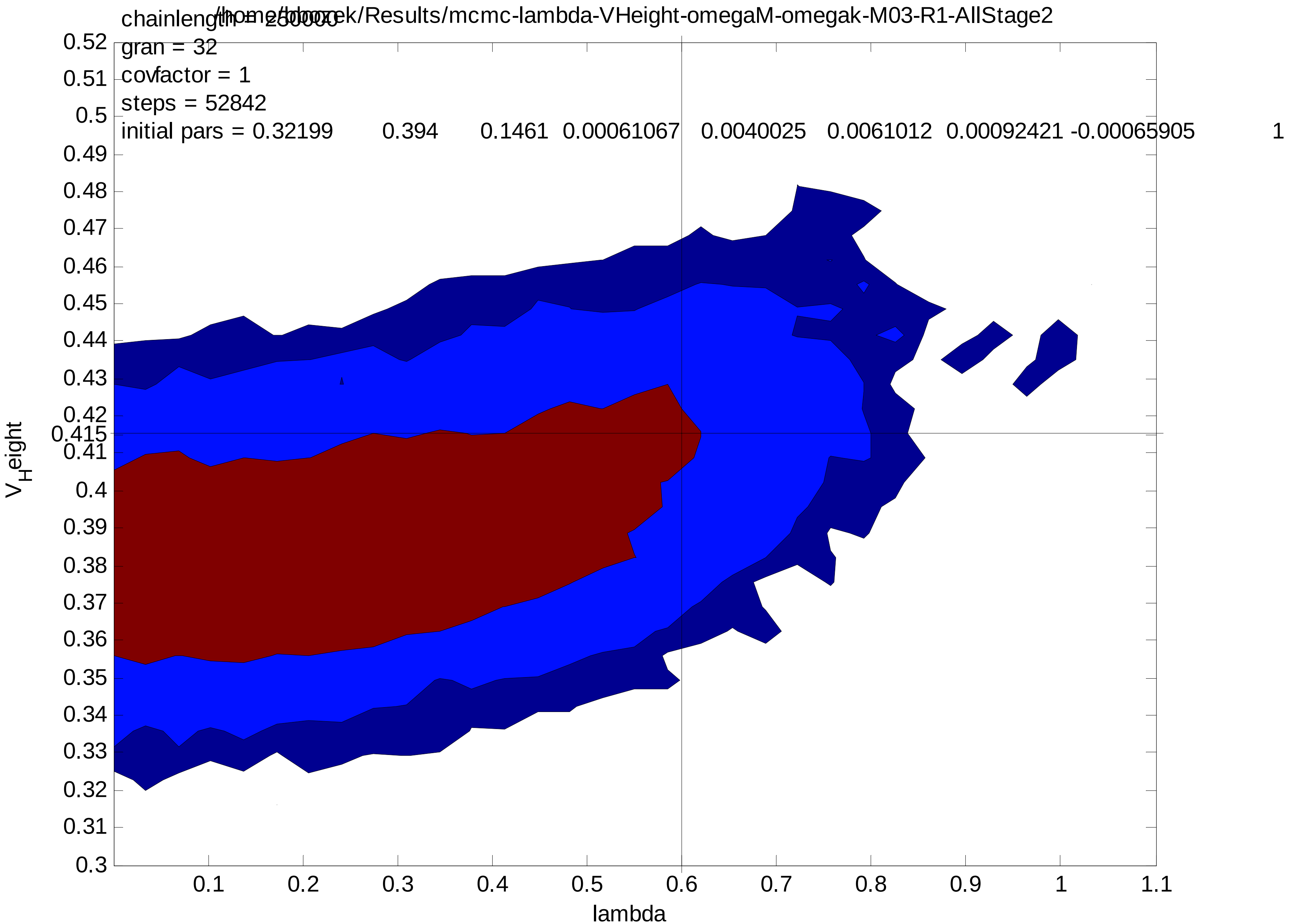


Stage 4 Space WL Opt; lin-a N_{Grid} = 9, z_{max} = 4, Tag = 044301
σ_i
f's
a
1
2
3
4
5
6
7
8
9



Stage 4 Space WL Opt; lin-a N_{Grid} = 16, z_{max} = 4, Tag = 054301
σ_i
f's
a
1
2
3
4
5
6
7
8
9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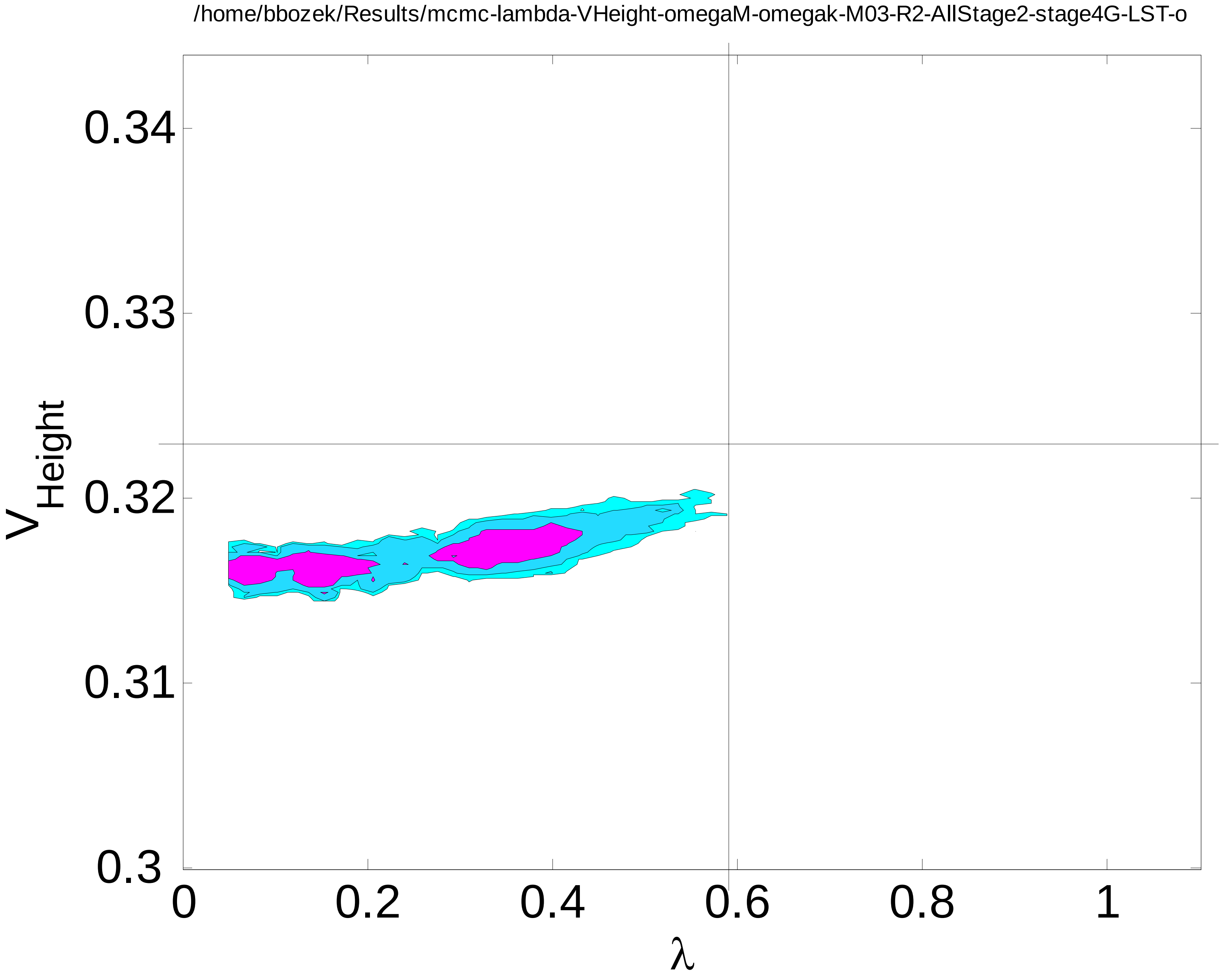
gran = 32
covfactor = 1
steps = 52842
initial pars = 0.32199 0.394 0.1461 0.00061067 0.0040025 0.0061012 0.00092421 -0.00065905 1
0.52
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.415
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.3
V_Height
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
lambda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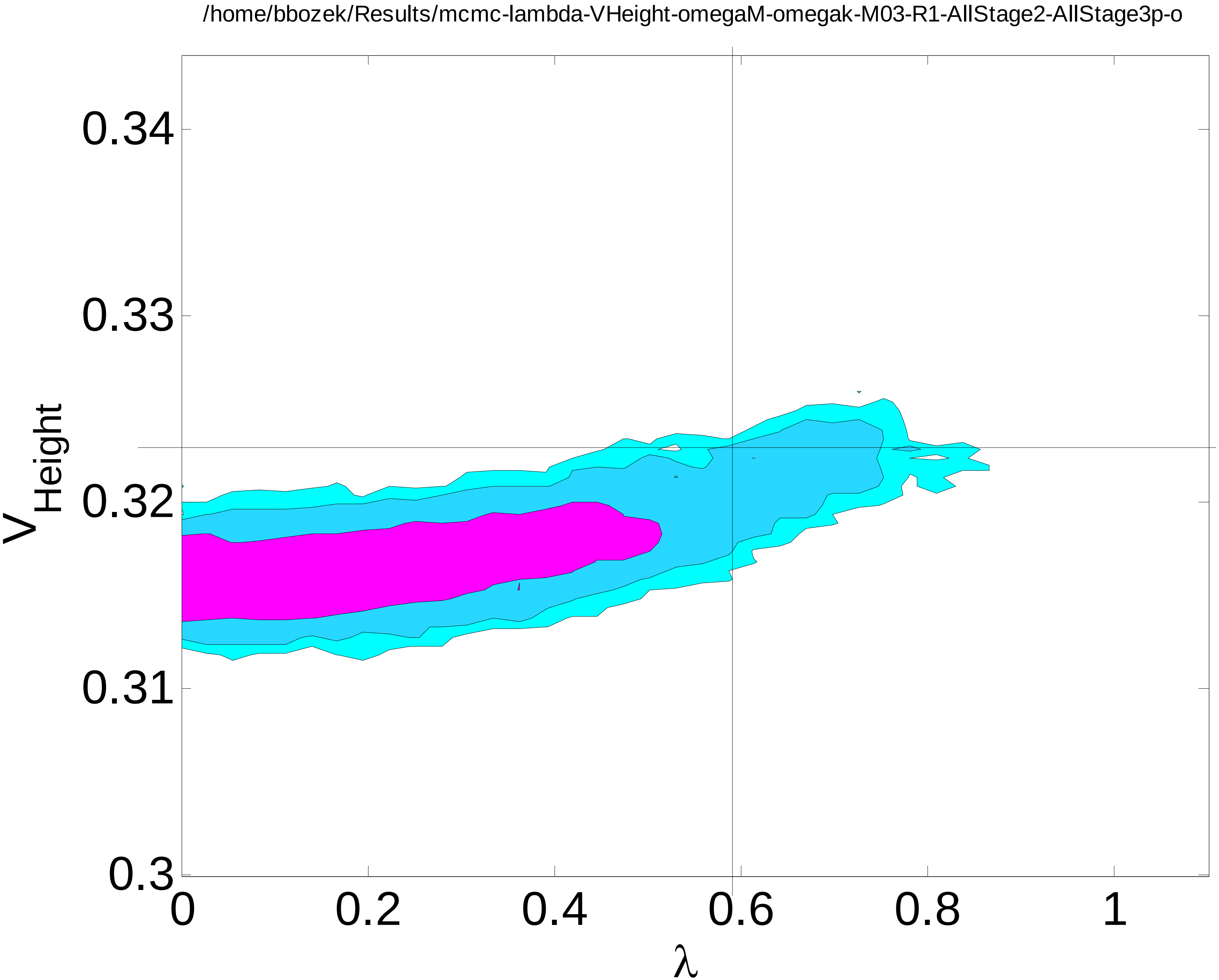
0.33
0.32
0.31
0.3
V_{Height}
0
0.2
0.4
0.6
0.8
1
λ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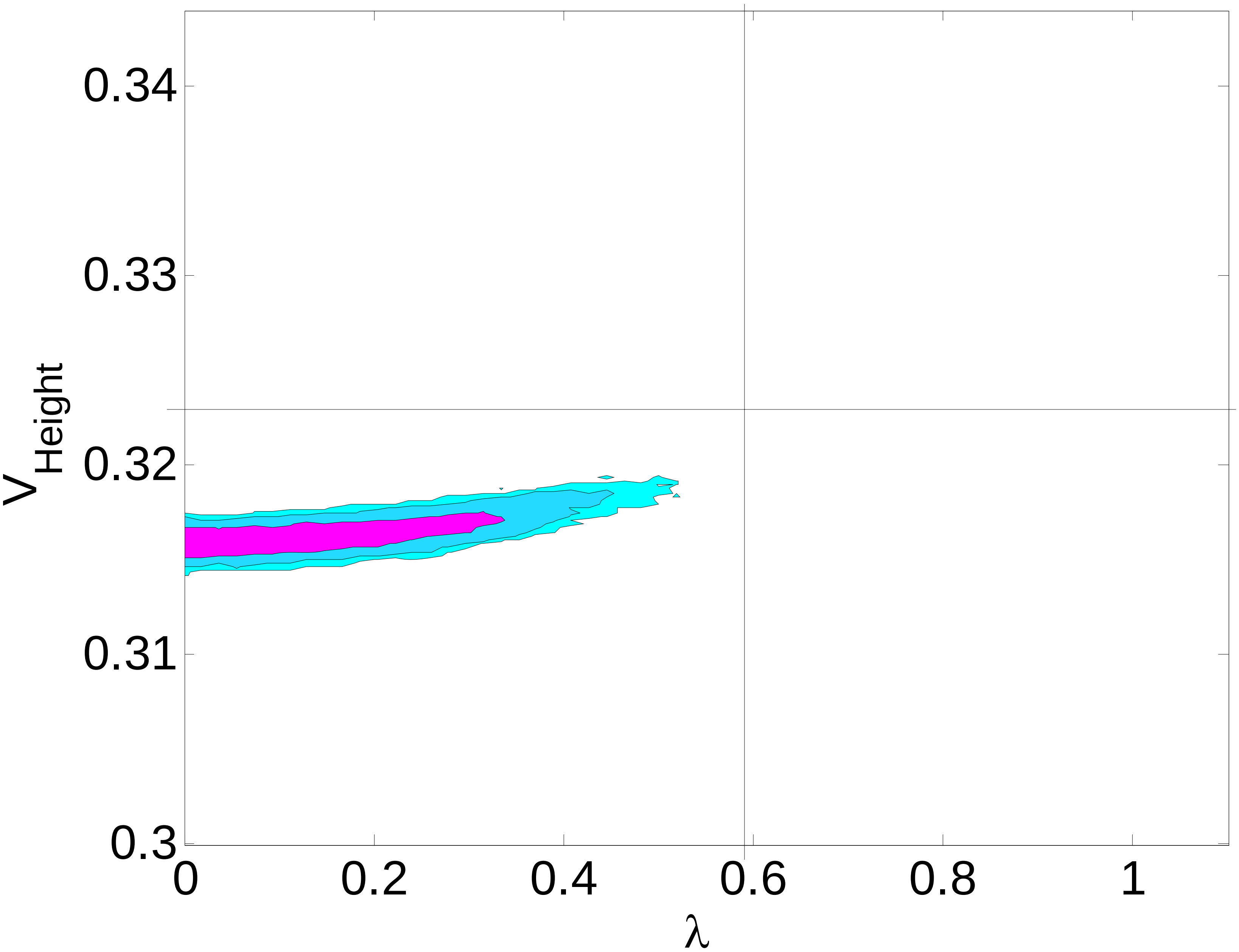
0.34
0.33
0.32
0.31
0.3
V_{Height}
0
0.2
0.4
0.6
0.8
1
λ

/home/bbozek/Results/mcmc-lambda-VHeight-omegaM-omegak-M03-R2-AllStage2-Stage4Space-o



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