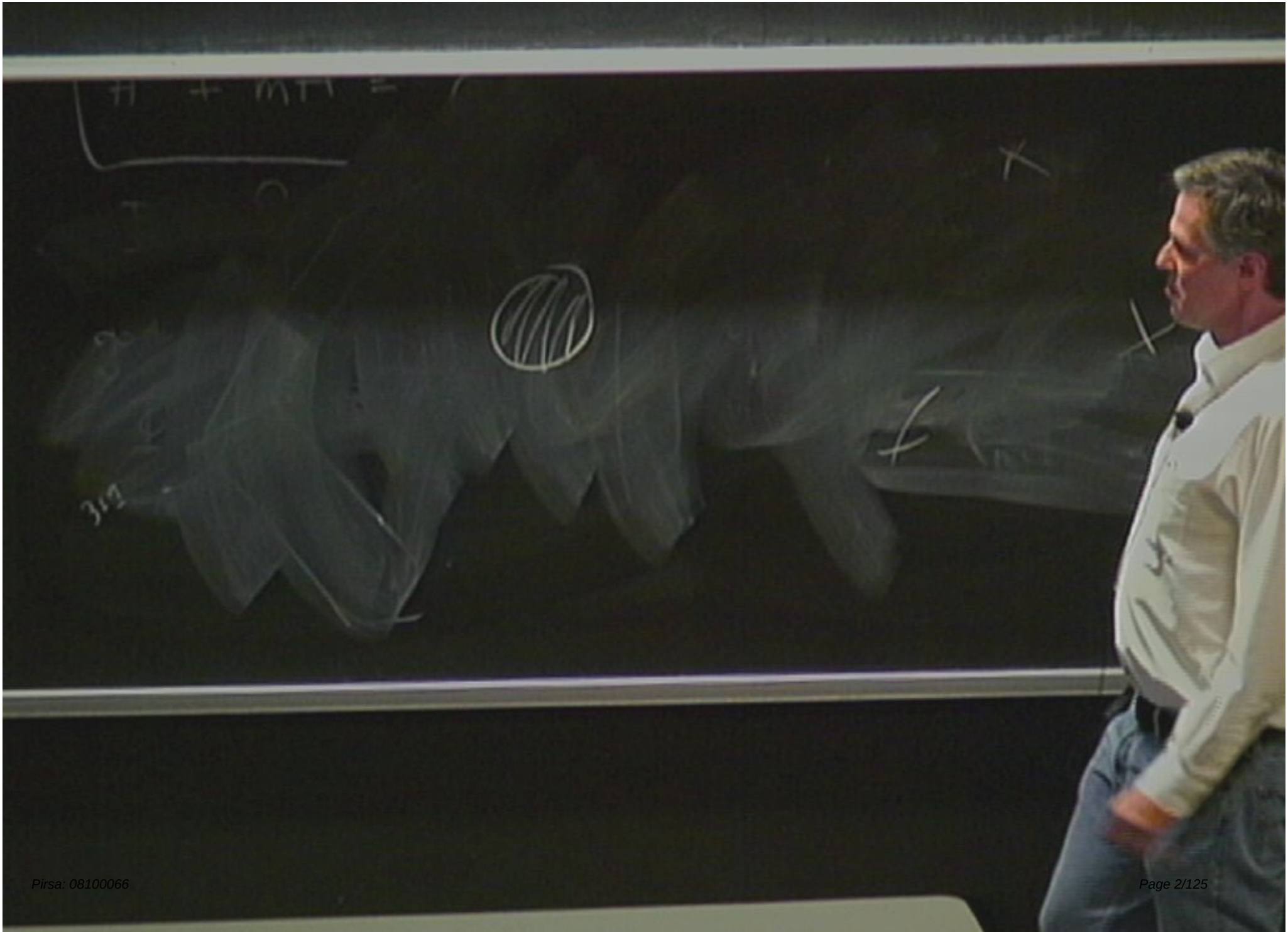
Title: What will future dark energy experiments tell us?

Date: Oct 23, 2008 11:30 AM

URL: http://pirsa.org/08100066

Abstract:



The Dark Energy Task Force (DETF)

➔ Created specific simulated data sets (Stage 2, Stage 3, Stage 4)

➔ Assessed their impact on our knowledge of dark energy as modeled with the *w0-wa* parameters

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

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New work, relevant to setting a concrete threshold for Stage 4

The Dark Energy Task F

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4)

➔ Assessed their im
modeled with the *w0*

NB: To make concrete comparisons this work ignores various possible improvements to the DETF data models.

(see for example J Newman, H Zhan *et al* & Schneider *et al*)

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DETF

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w_a
Ω_{DE}
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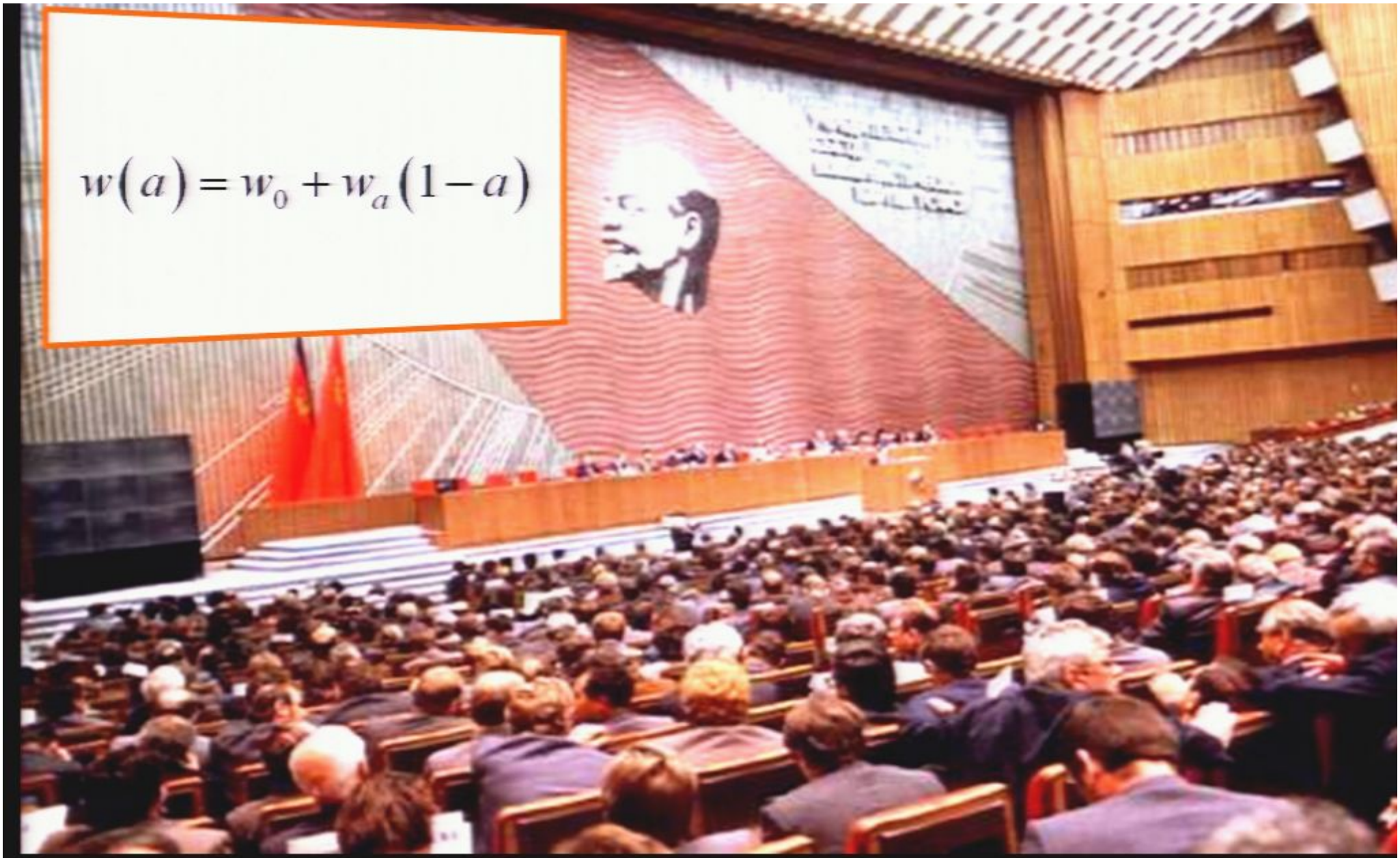
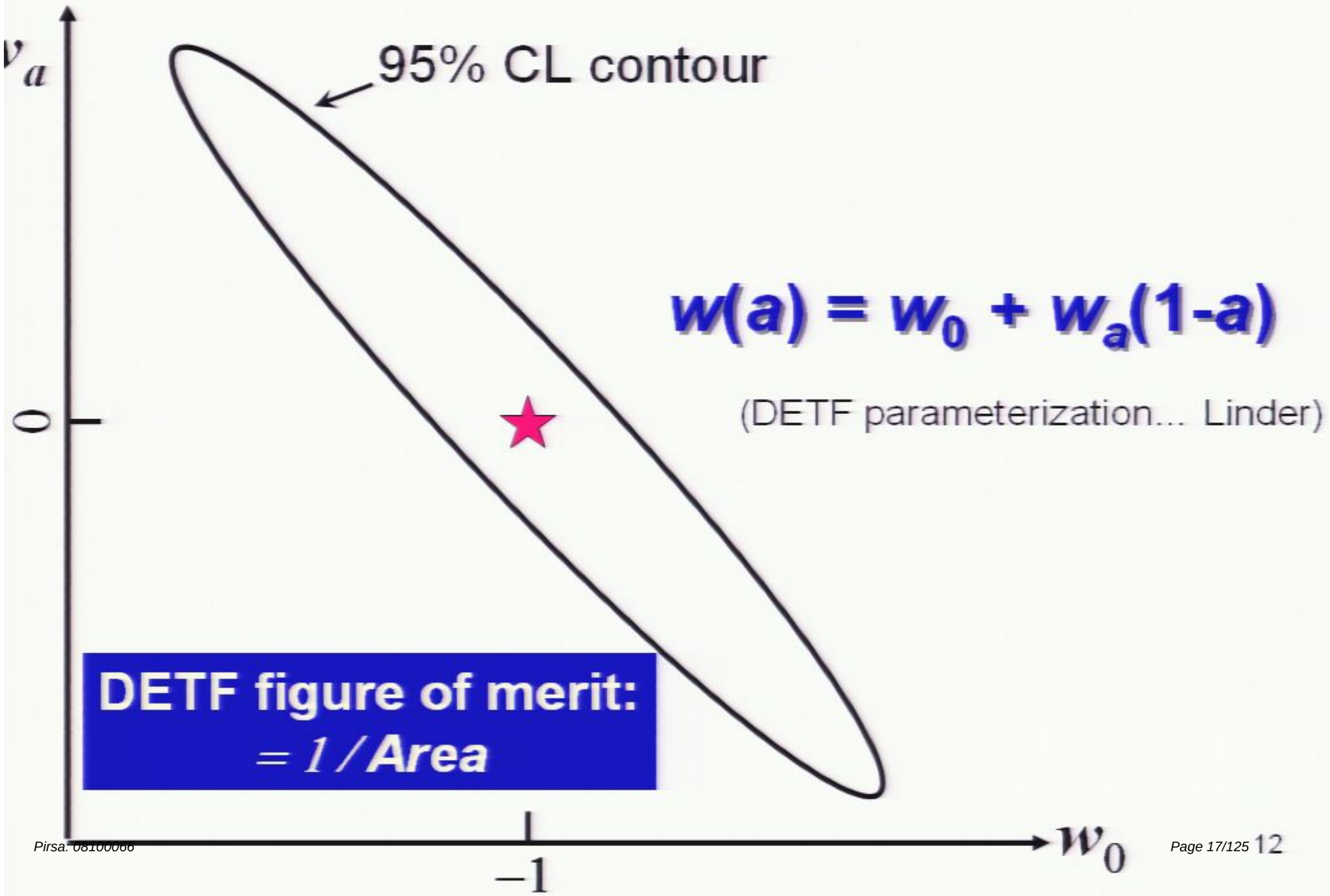


$< ?$

…but these parameters come out very well from this analysis

Review


w_a
95% CL contour
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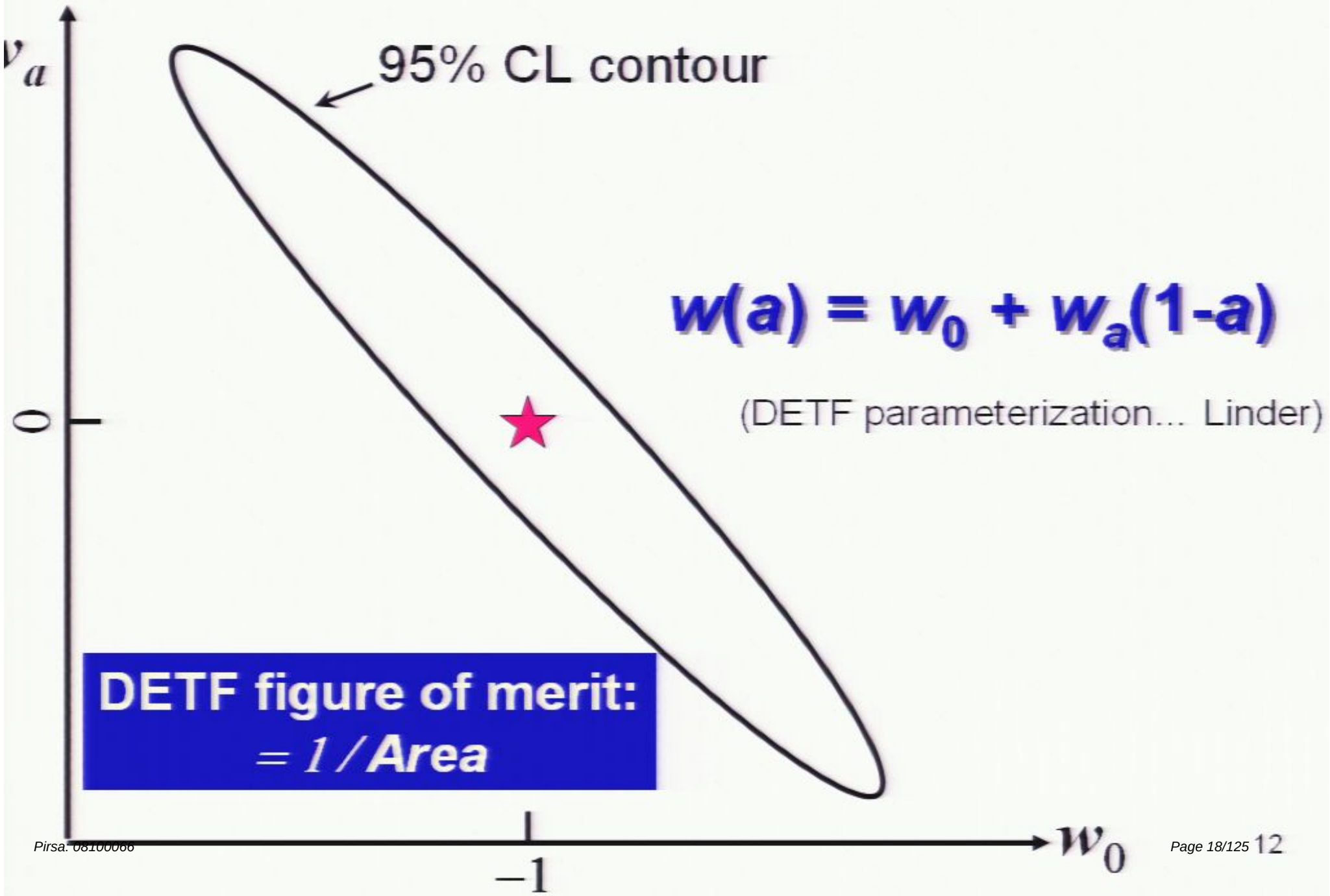
(DETF parameterization... Linder)
0
DETF figure of merit:
$= 1 / \mathrm{Area}$
-1
w_0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The DETF stages (data models constructed for each one)

Stage 2: Underway

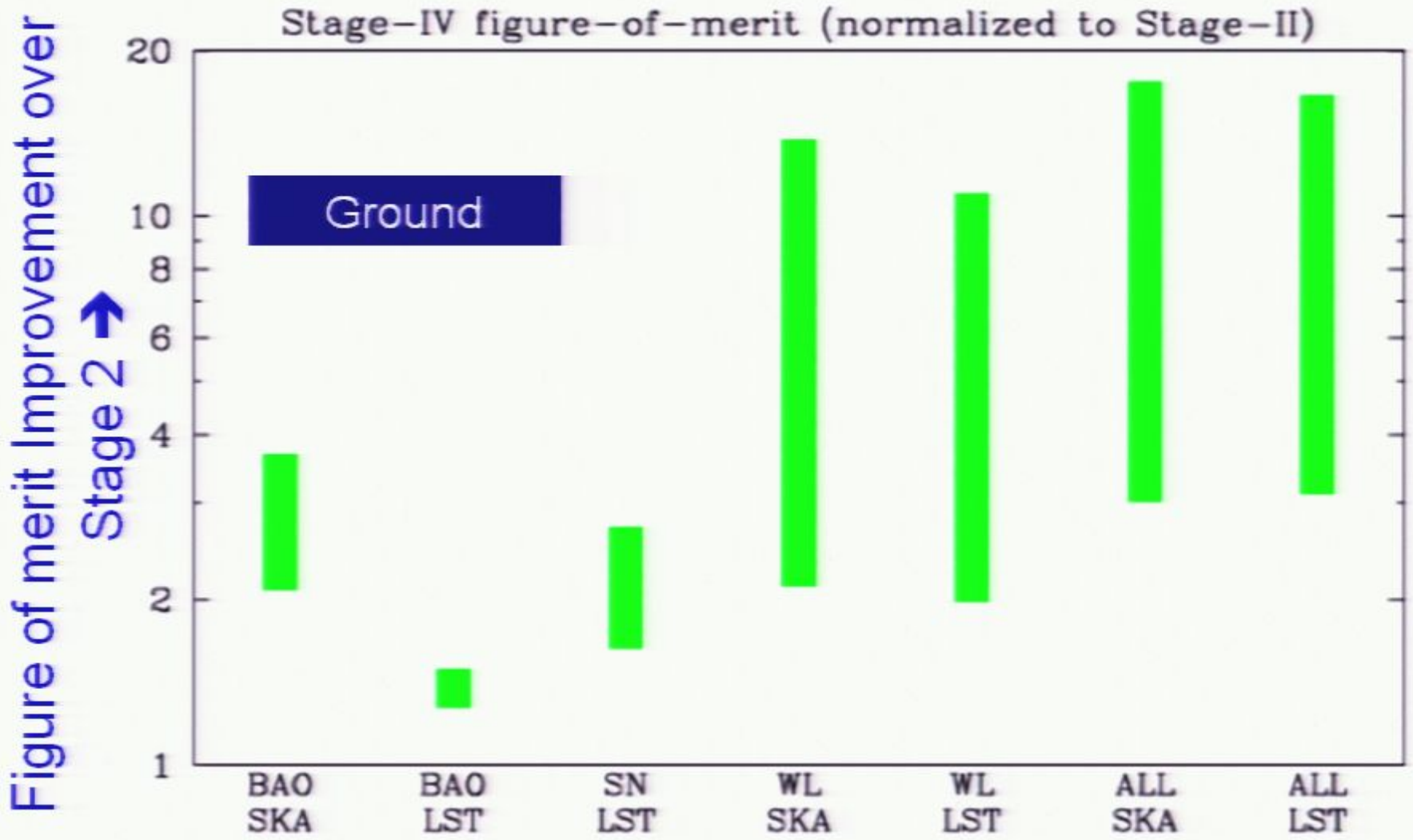
Stage 3: Medium size/term projects

Stage 4: Large longer term projects (ie JDEM, LST)

DETF modeled

- SN
- Weak Lensing
- Baryon Oscillation
- Cluster data

DETF Projections



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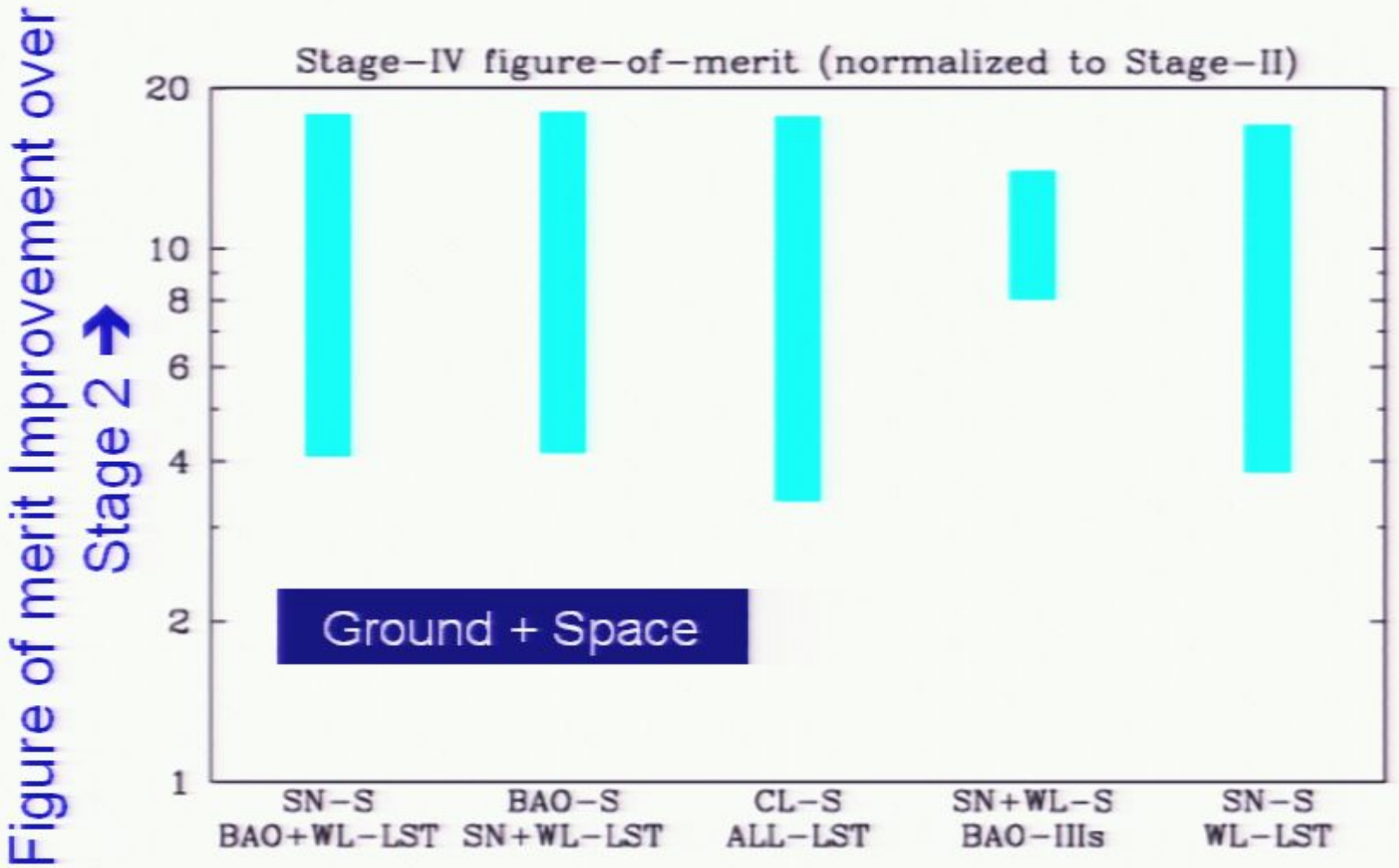
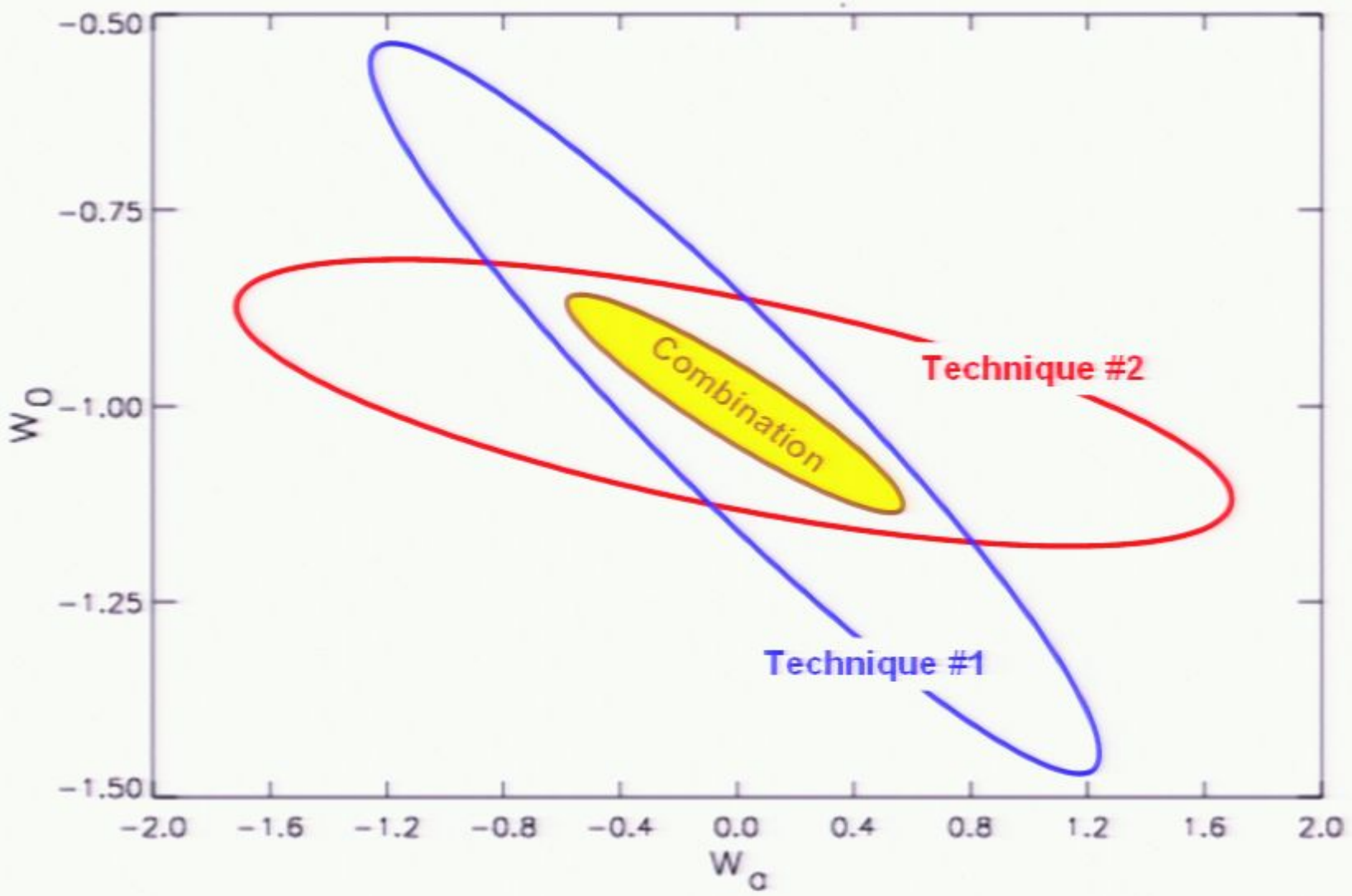


A technical point: The role of correlations



From the DETF Executive Summary

One of our main findings is that no single technique can answer the outstanding questions about dark energy: combinations of at least two of these techniques must be used to fully realize the promise of future observations.

Already there are proposals for major, long-term (Stage IV) projects incorporating these techniques that have the promise of increasing our figure of merit by a factor of ten beyond the level it will reach with the conclusion of current experiments. What is urgently needed is a commitment to fund a program comprised of a selection of these projects. The selection should be made on the basis of critical evaluations of their costs, benefits, and risks.

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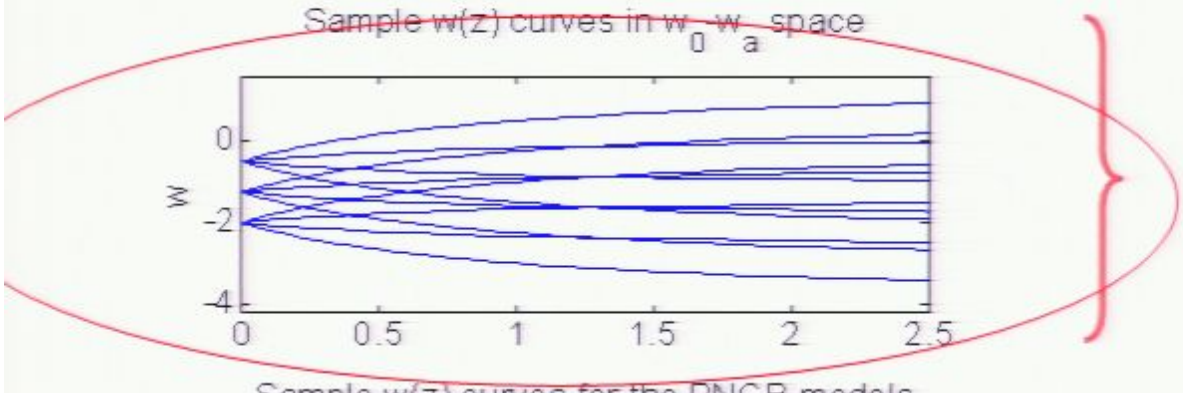
How good is the w(a) ansatz?



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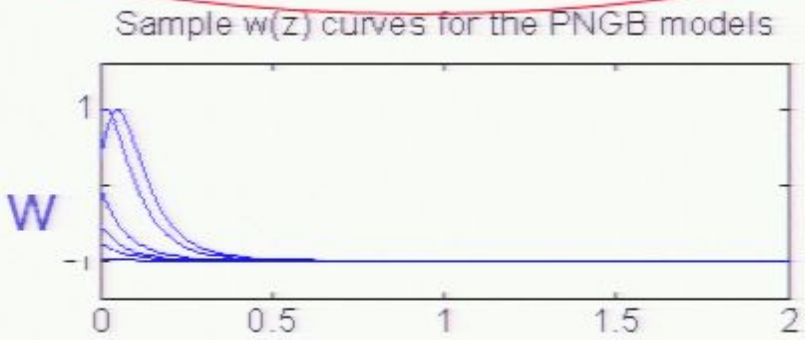
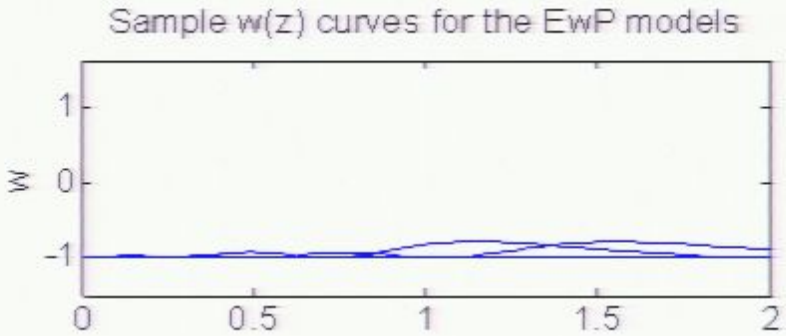
w0-wa can only do these





z

DE models can do this
(and much more)

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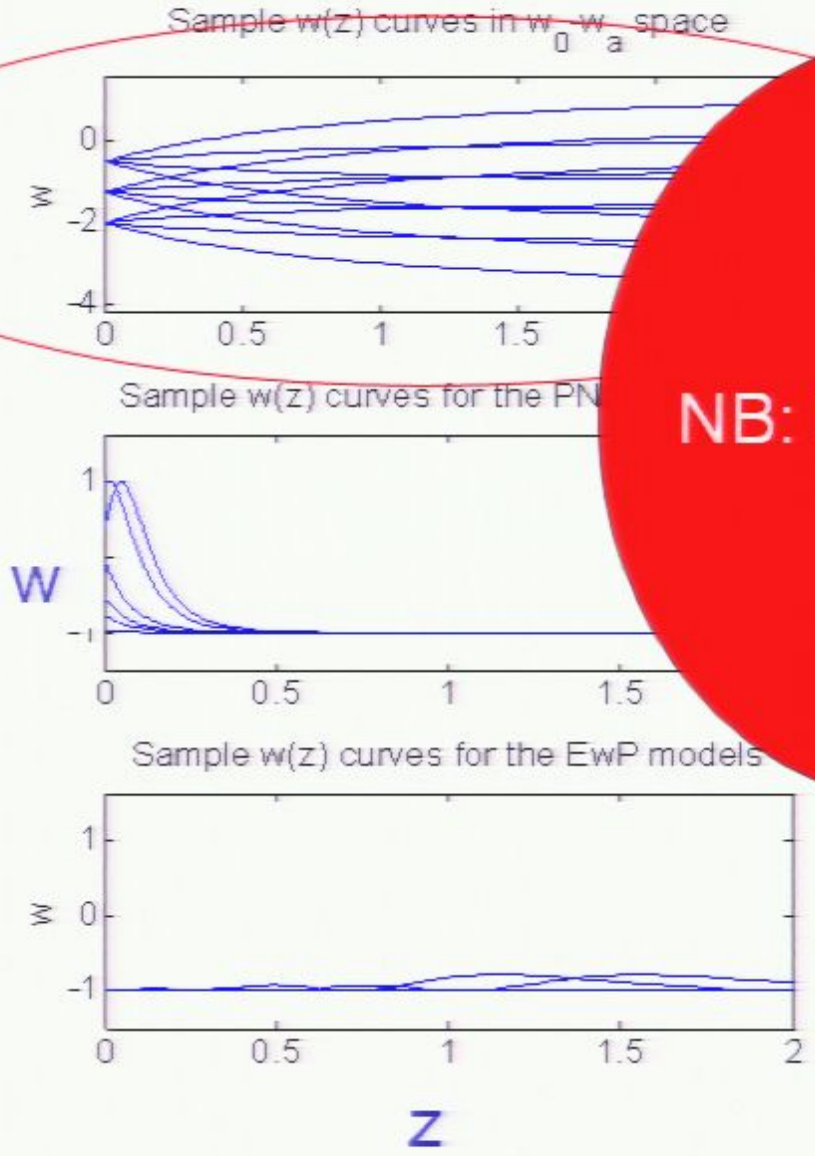


NB: Better than

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

va can only do these

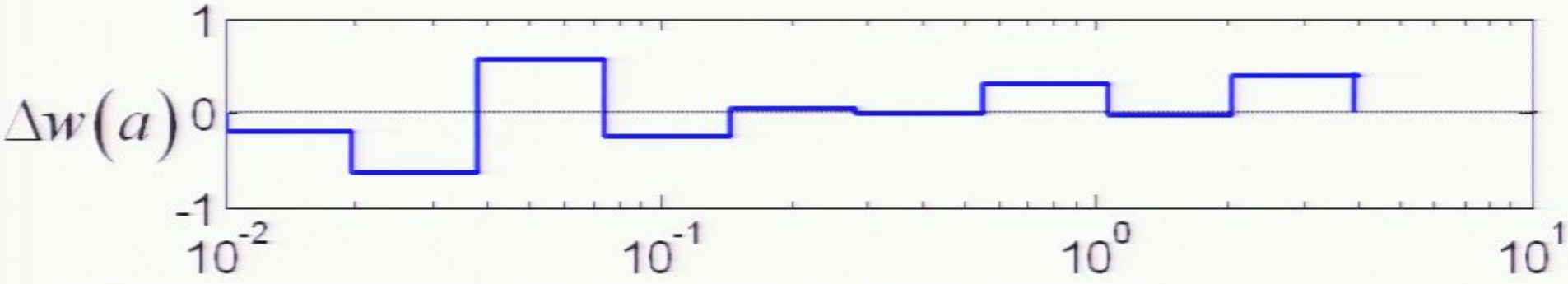
$$w(a) = w_0$$

& flat

DE models can do this

(and much more)

Try (9)D stepwise constant w(a)



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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/MoreInfo0608269/

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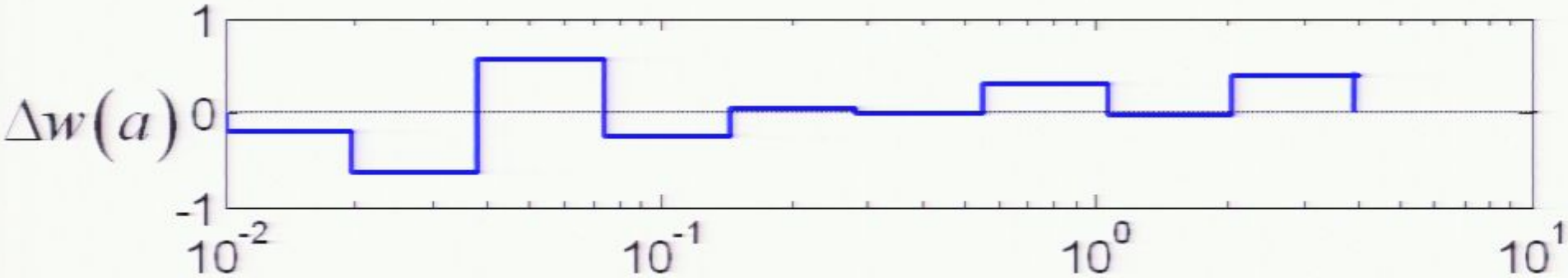

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Used by

Huterer & Turner;
Huterer & Starkman;
Knox et al;
Crittenden & Pogosia
Linder; Reiss et al;
Krauss et al
de Putter & Linder;
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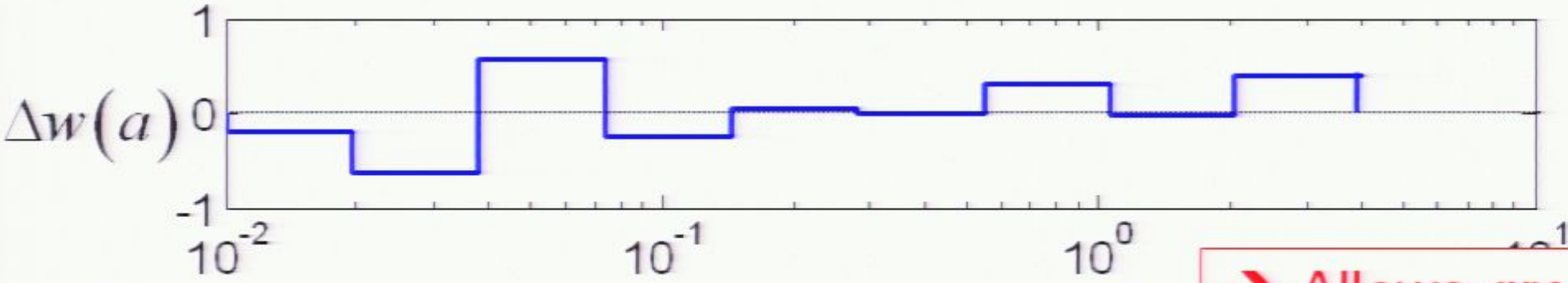

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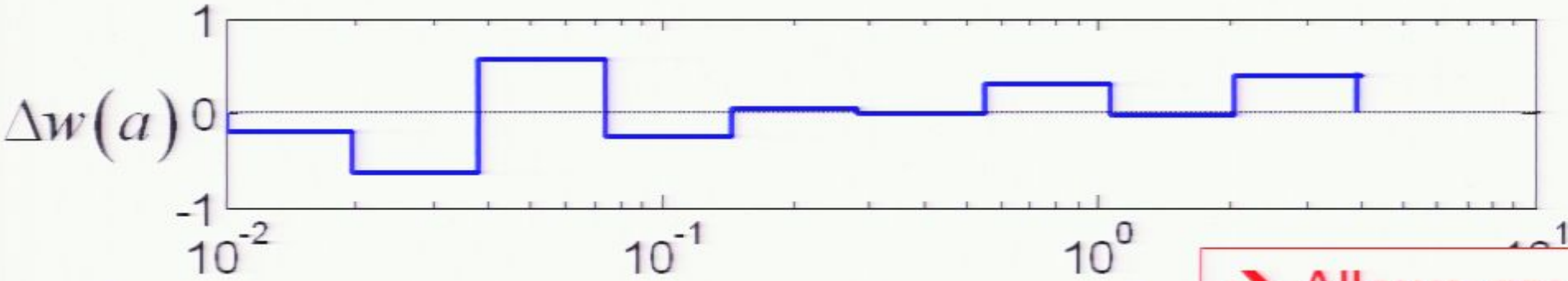

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"Convergence"

AA & G Bernstein 2006

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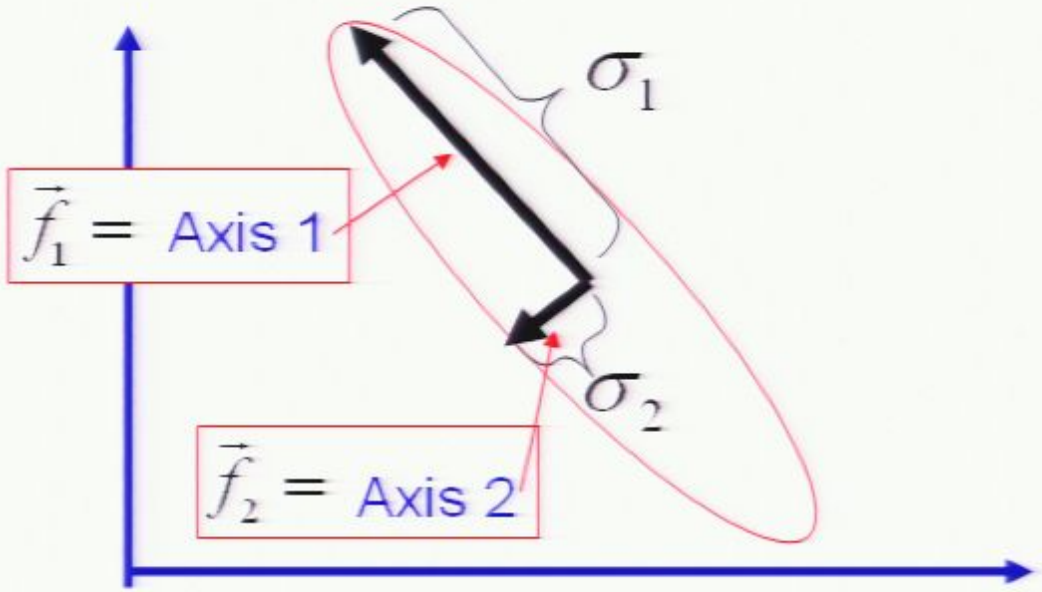
A: In terms of 9 principle axes $\vec{f}_i$ and corresponding 9 errors σ_i:

2D illustration:



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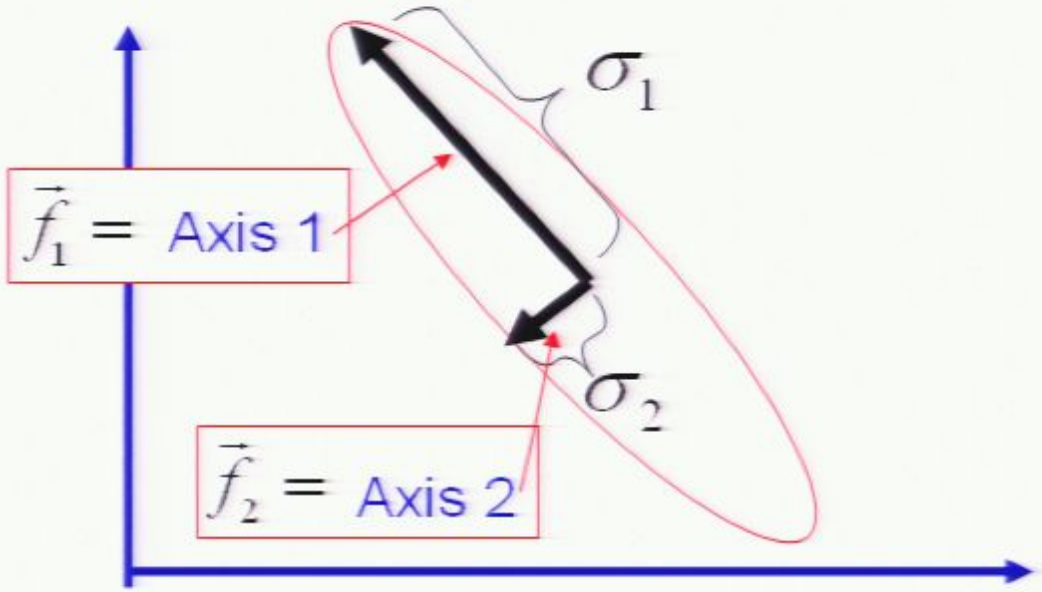
Principle component analysis

2D illustration:



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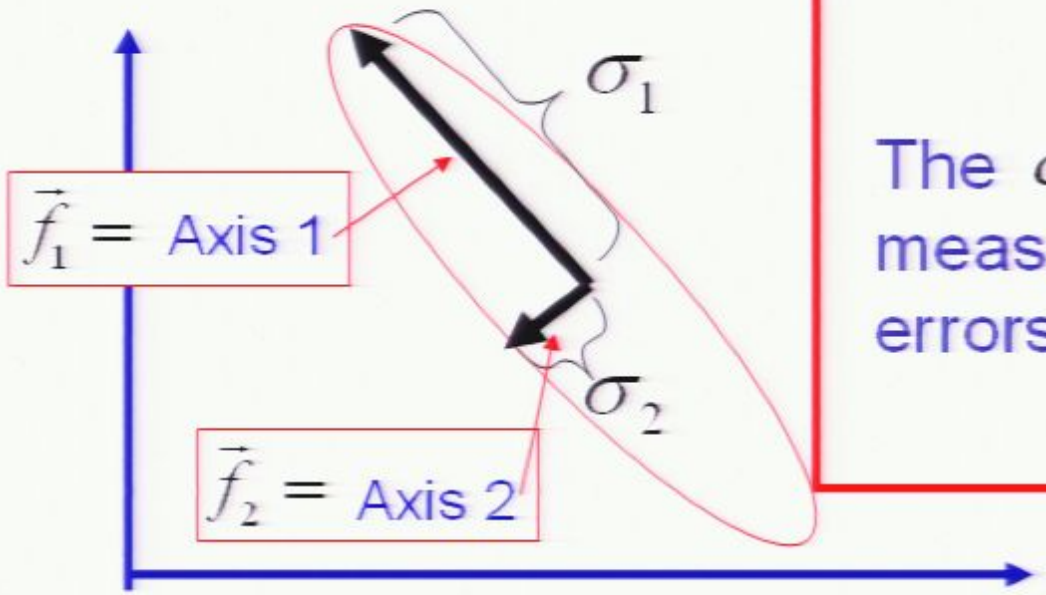

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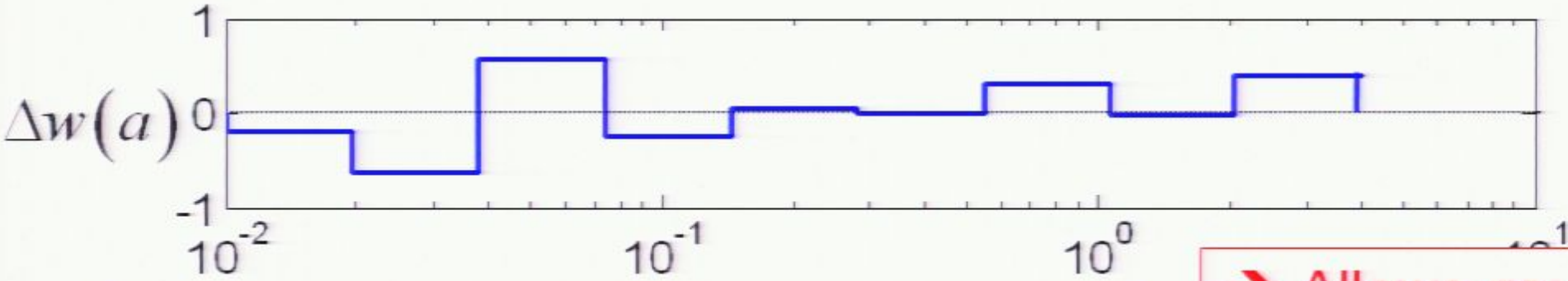

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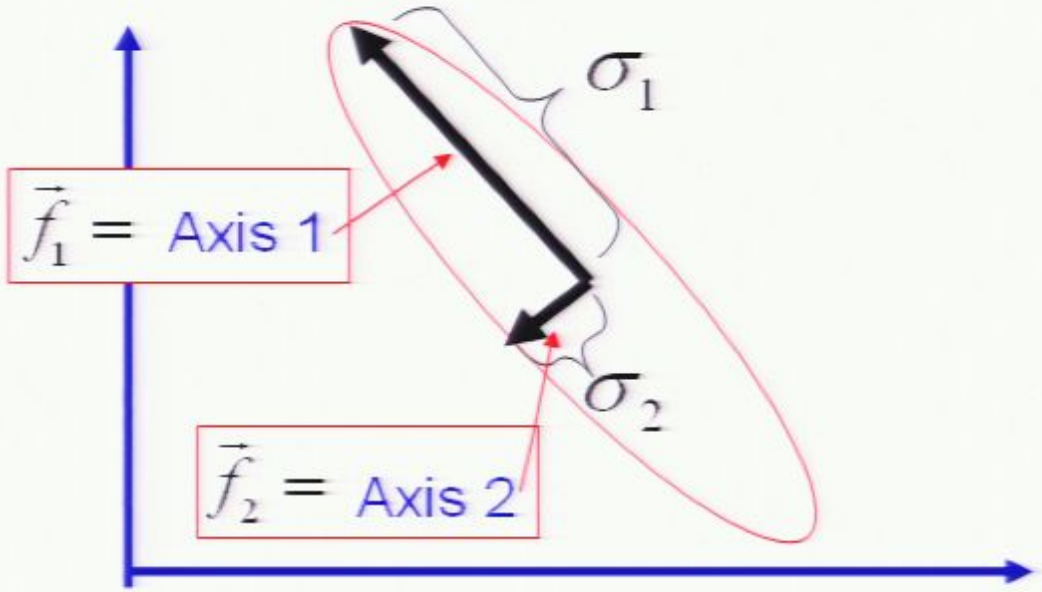

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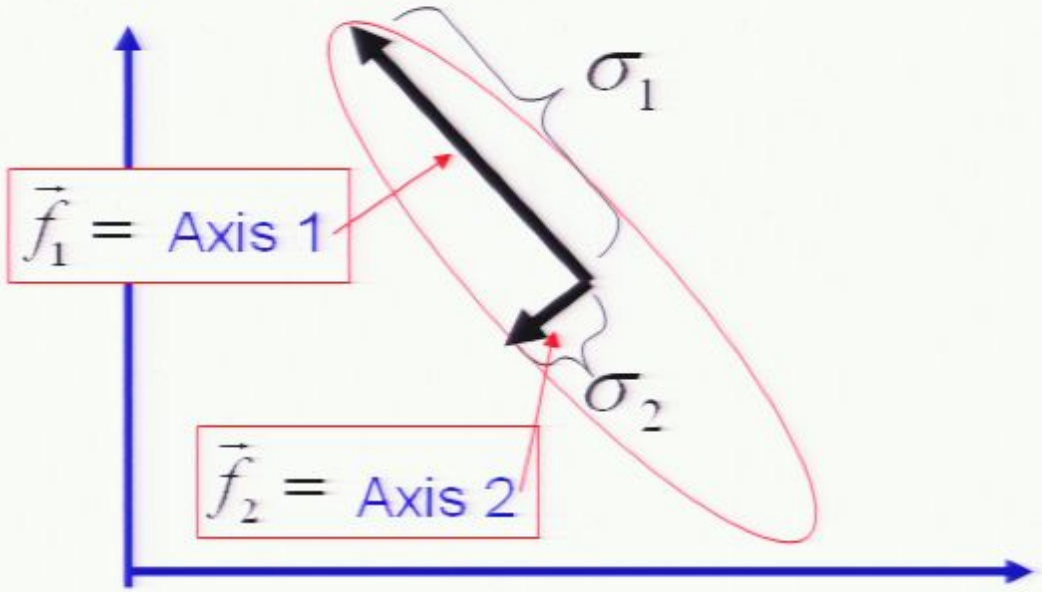

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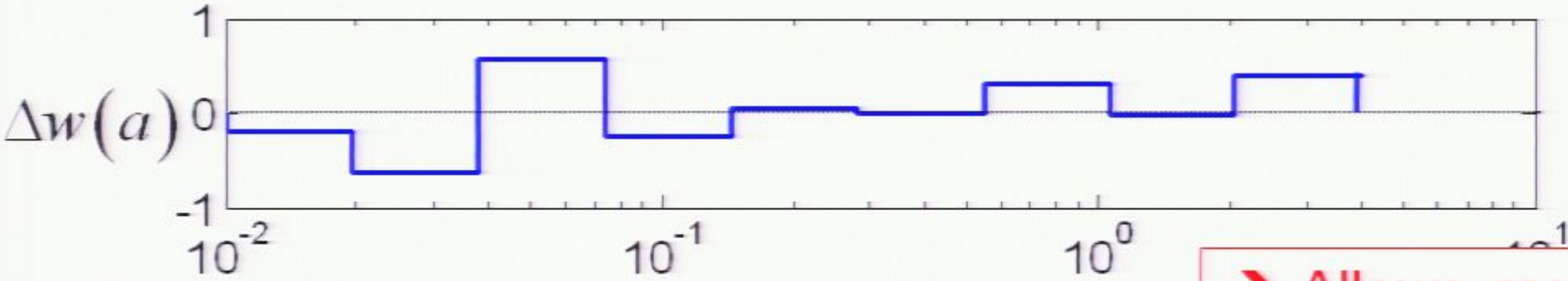

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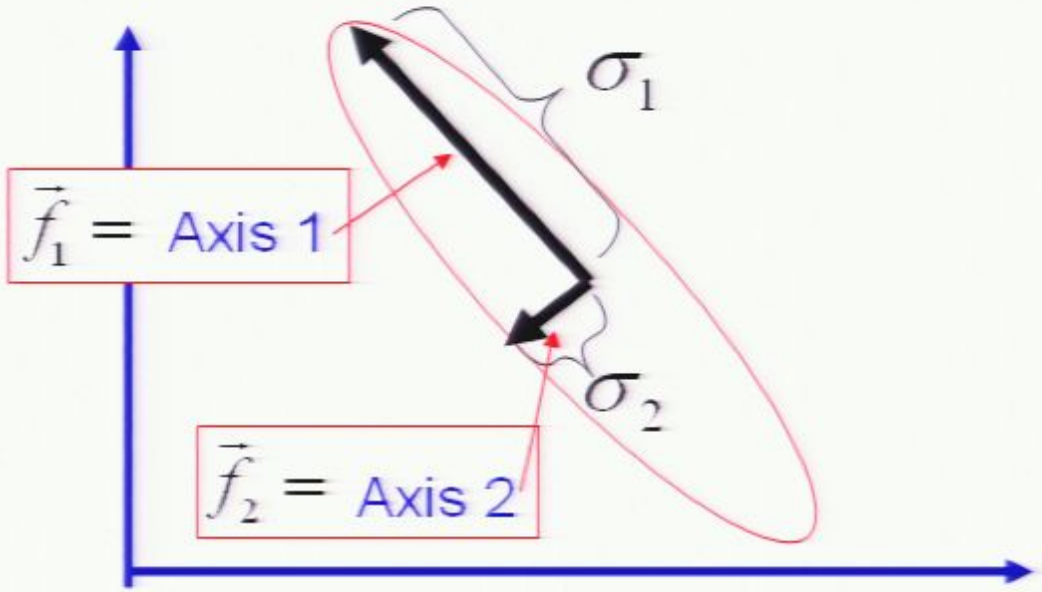

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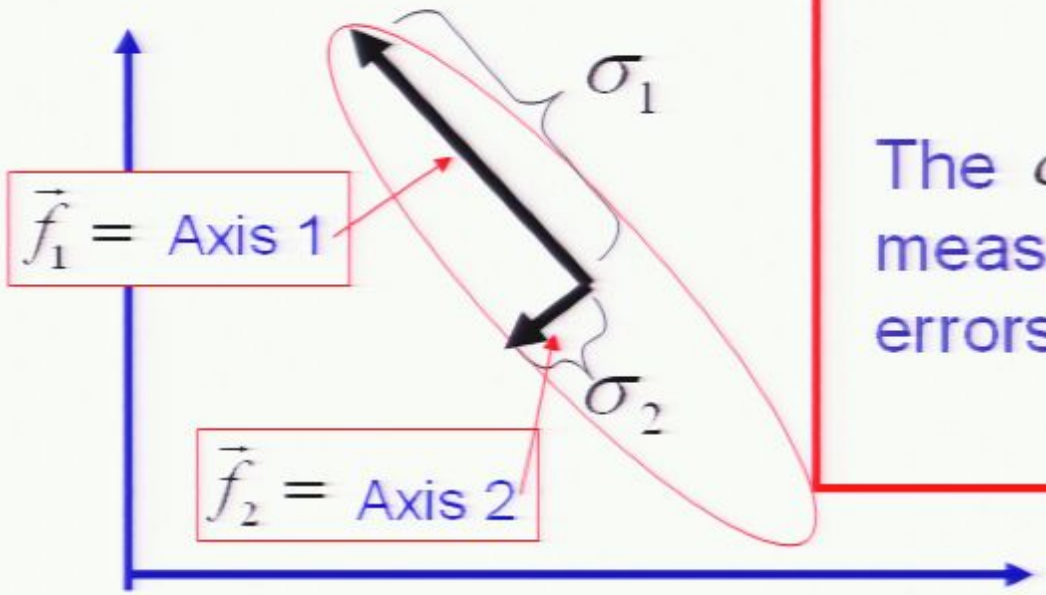

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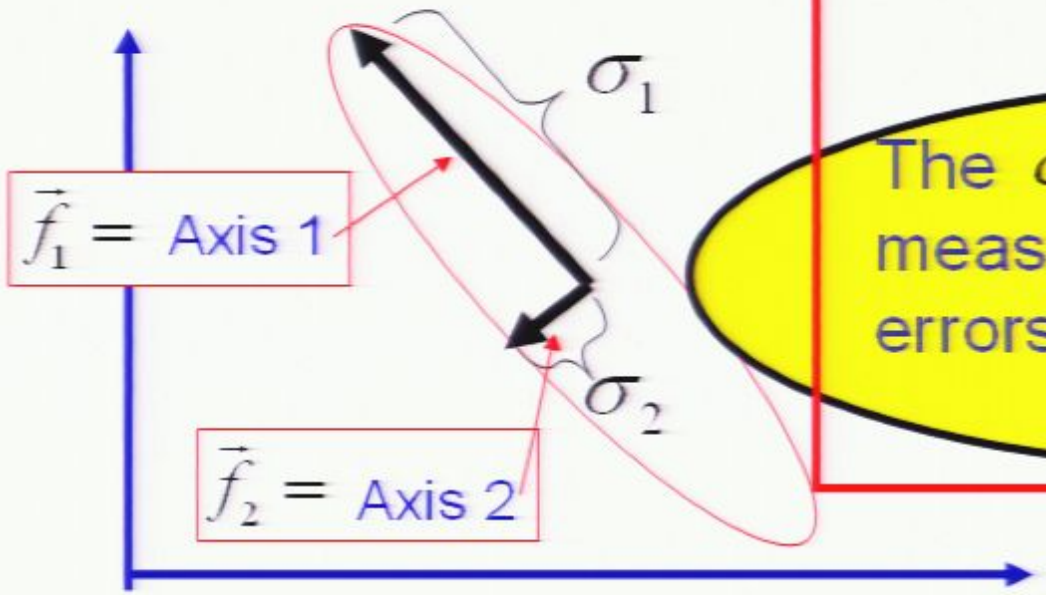

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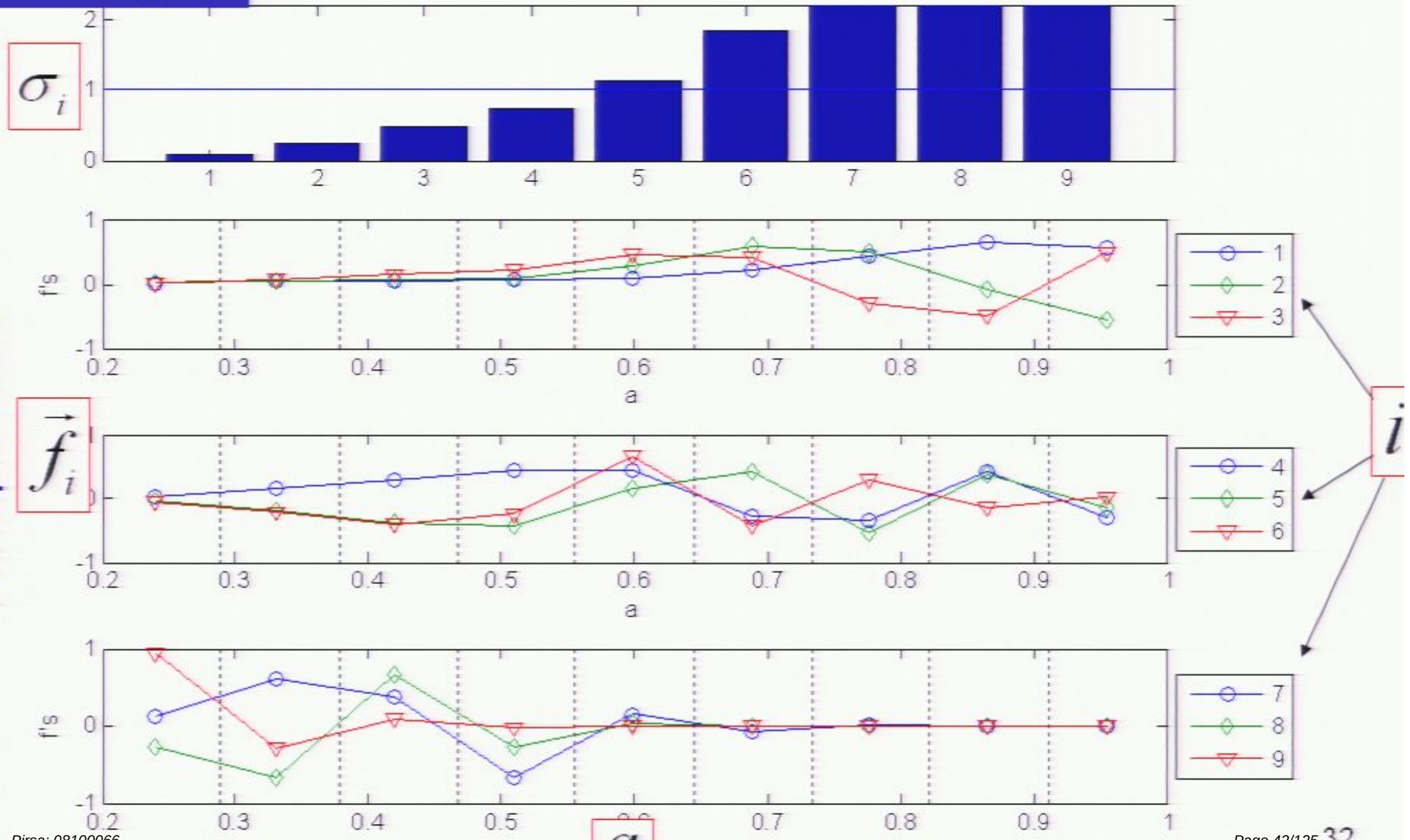
Characterizing 9D ellipses by principle axes and corresponding errors

DETF stage 2



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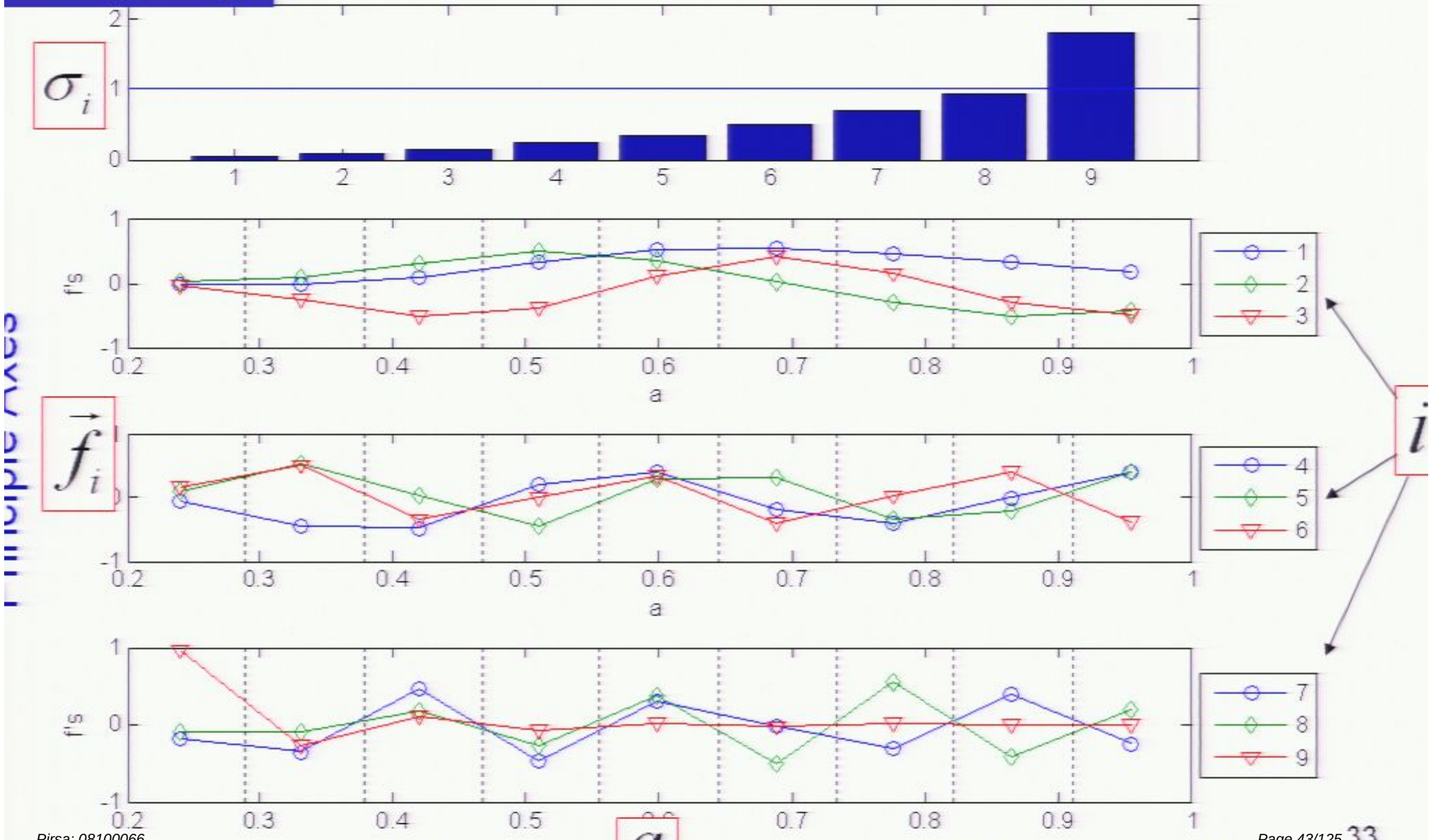

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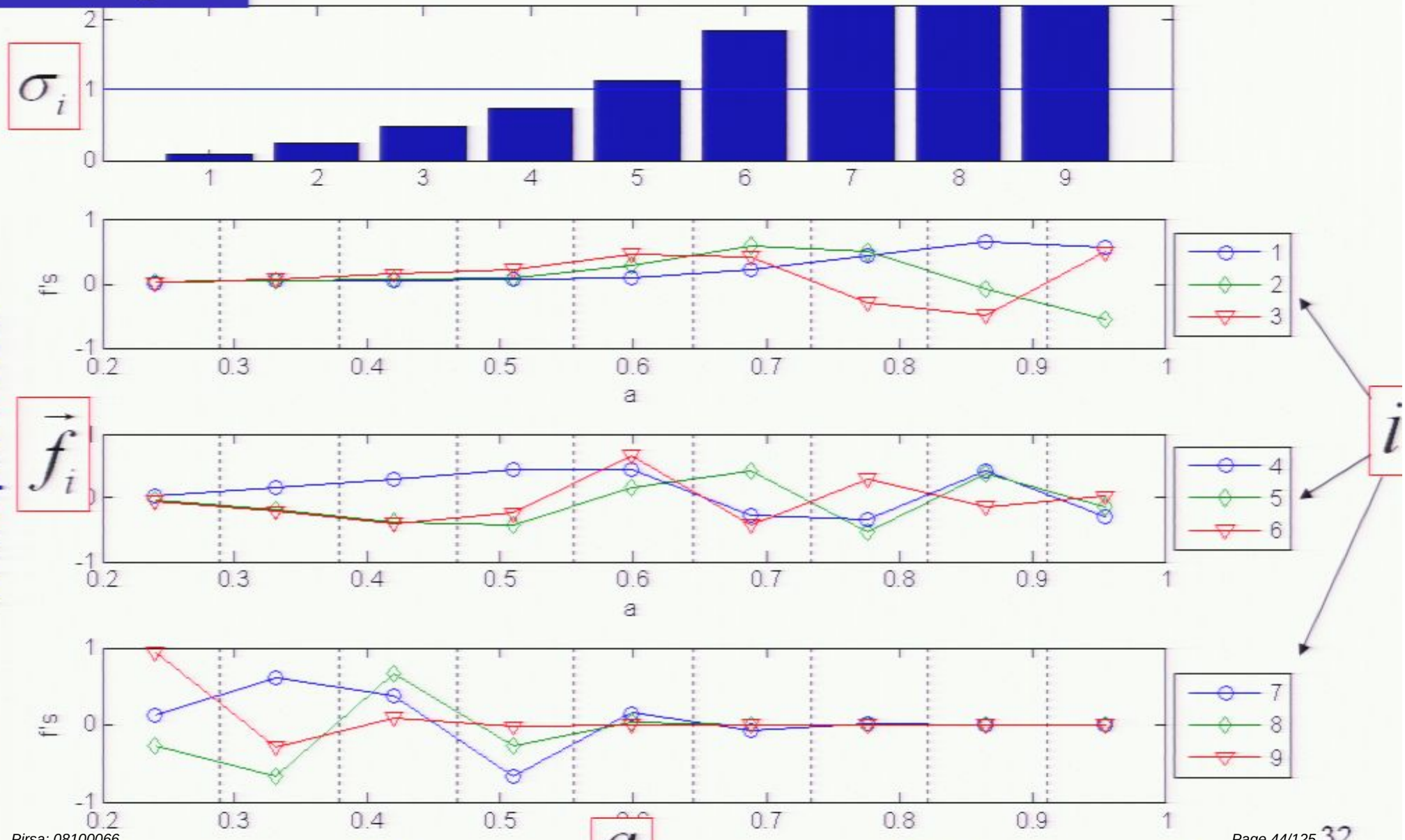
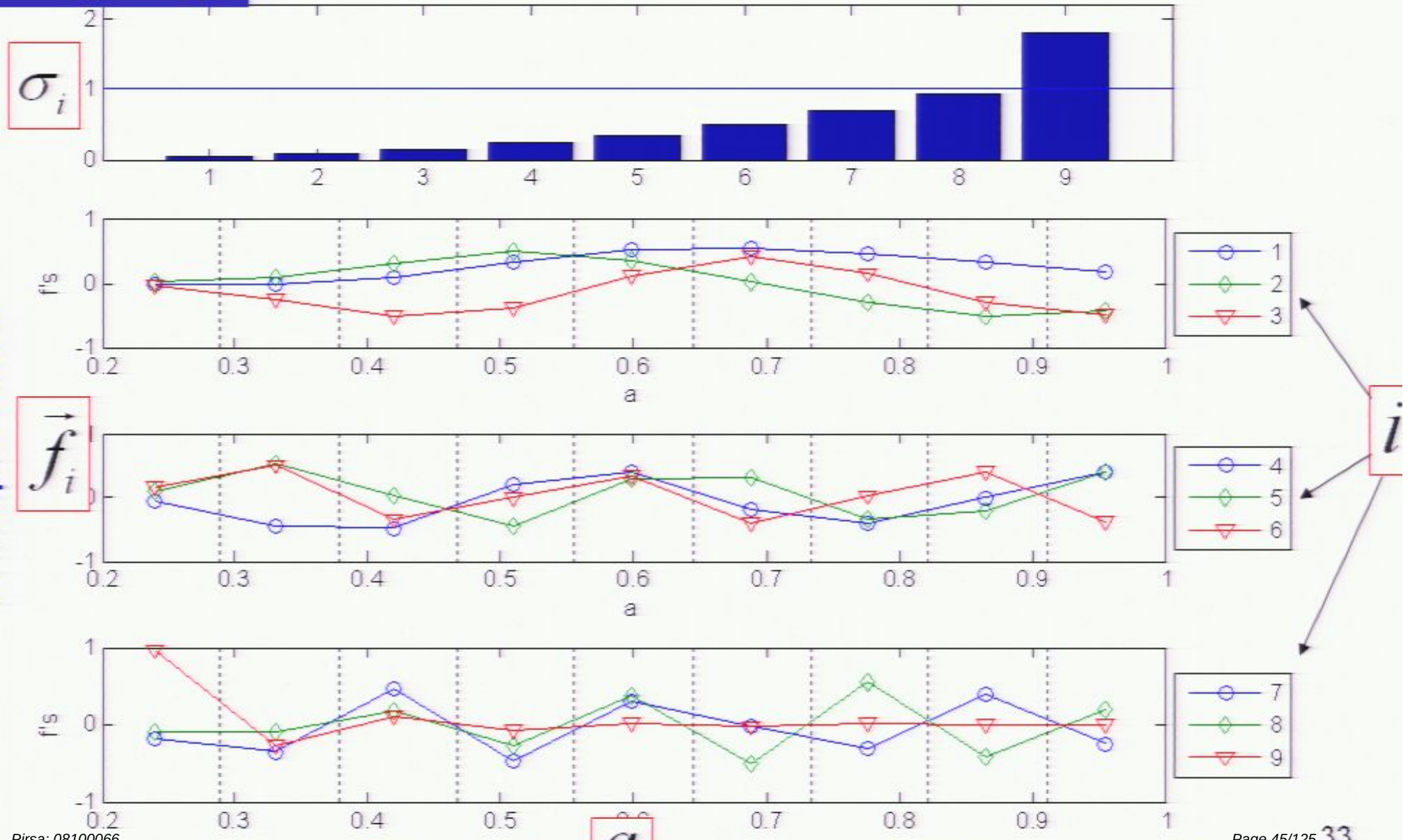


Ellipse axes

z-=4 z =1.5 a z =0.25 z =0

Characterizing 9D ellipses by principle axes and corresponding errors

L Stage 4 Opt



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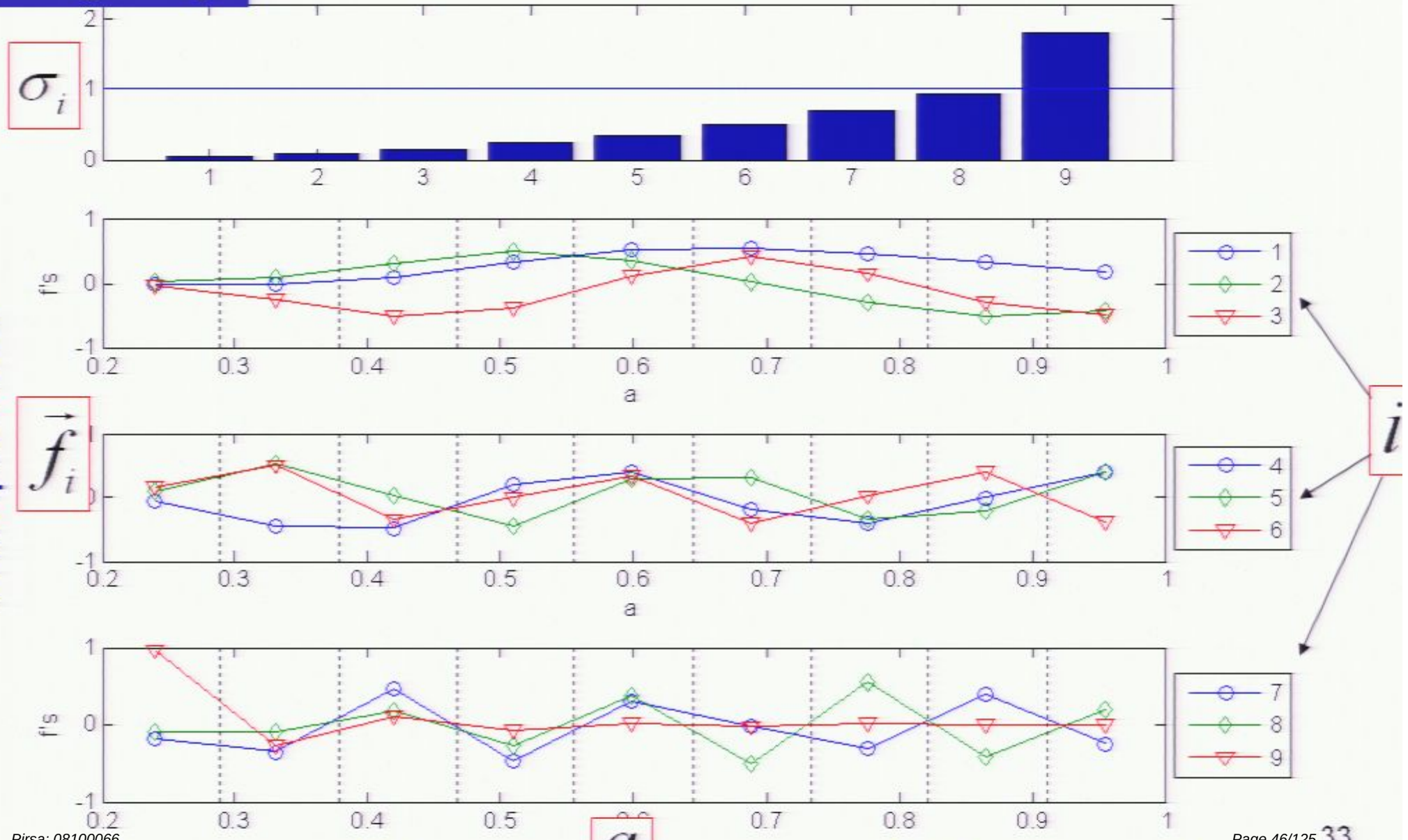

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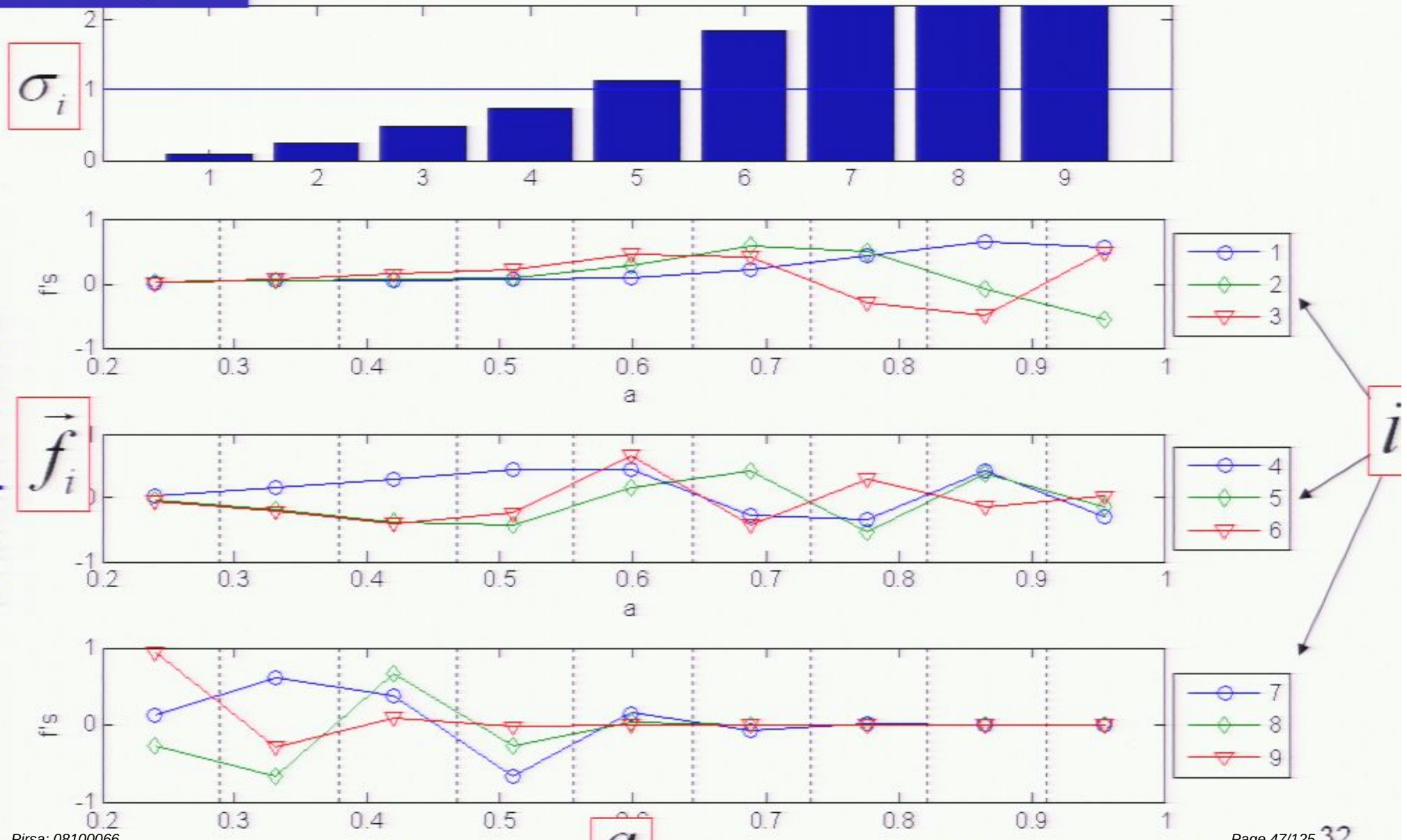

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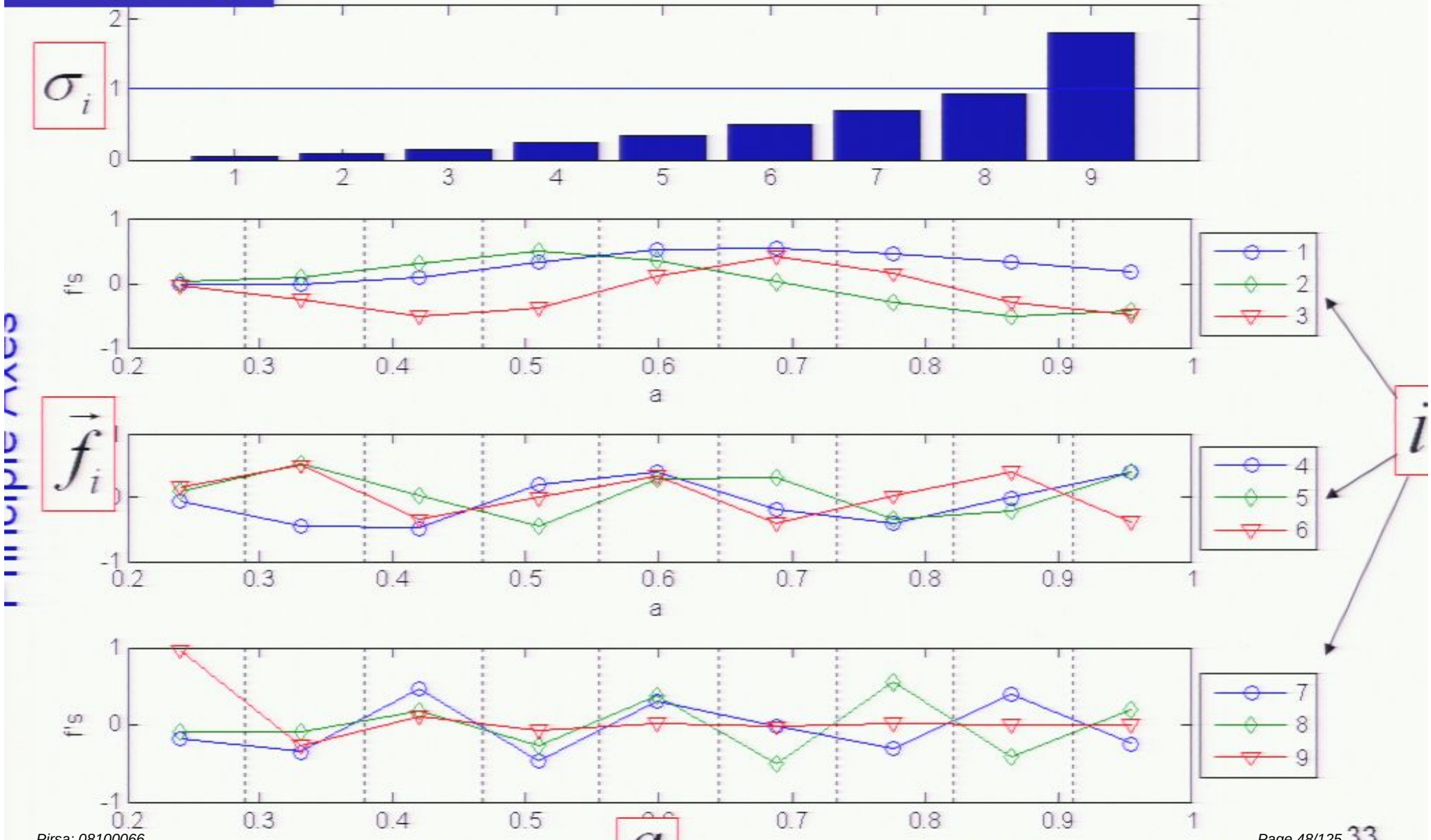
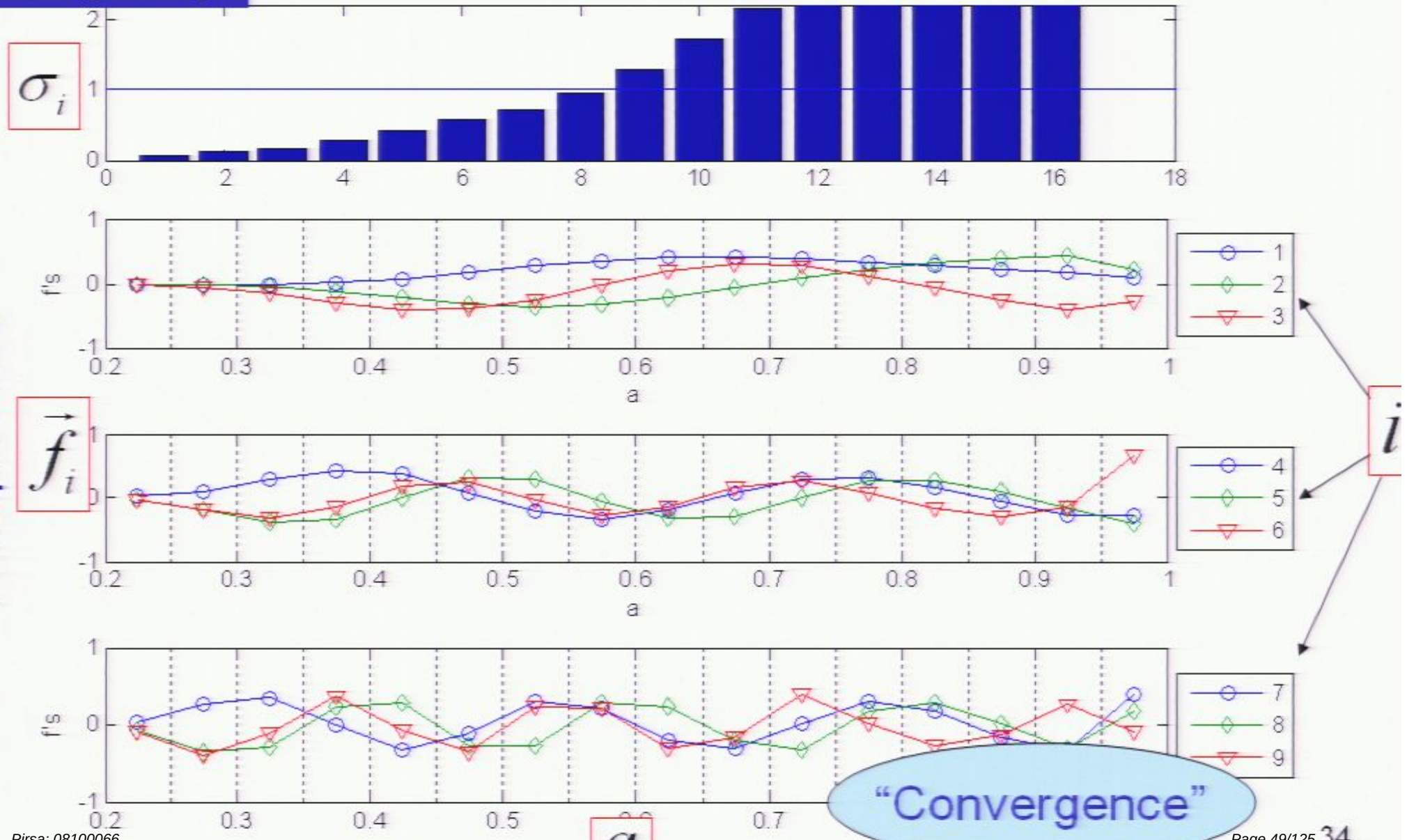
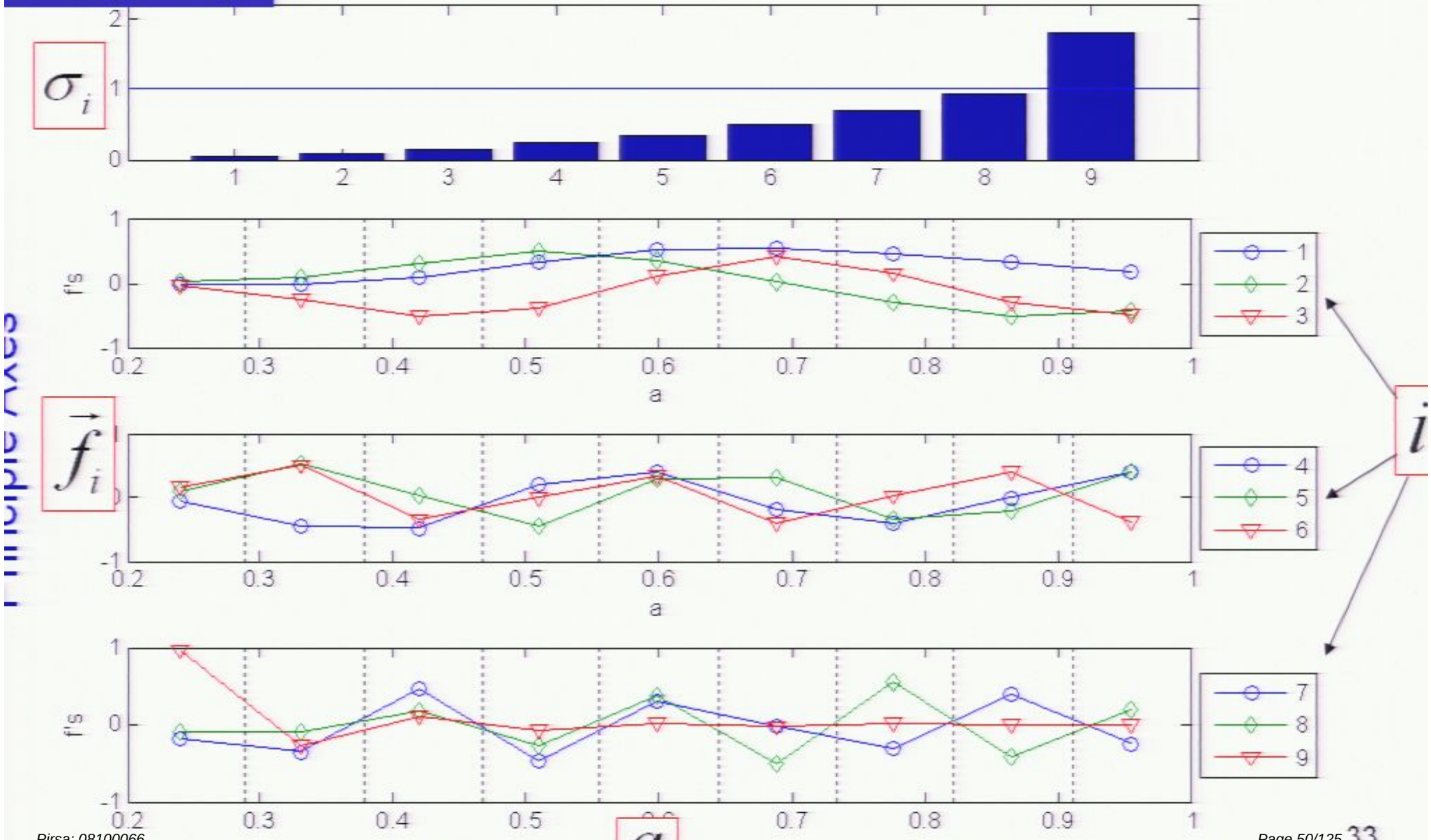


Characterizing 9D ellipses by principle axes and corresponding errors



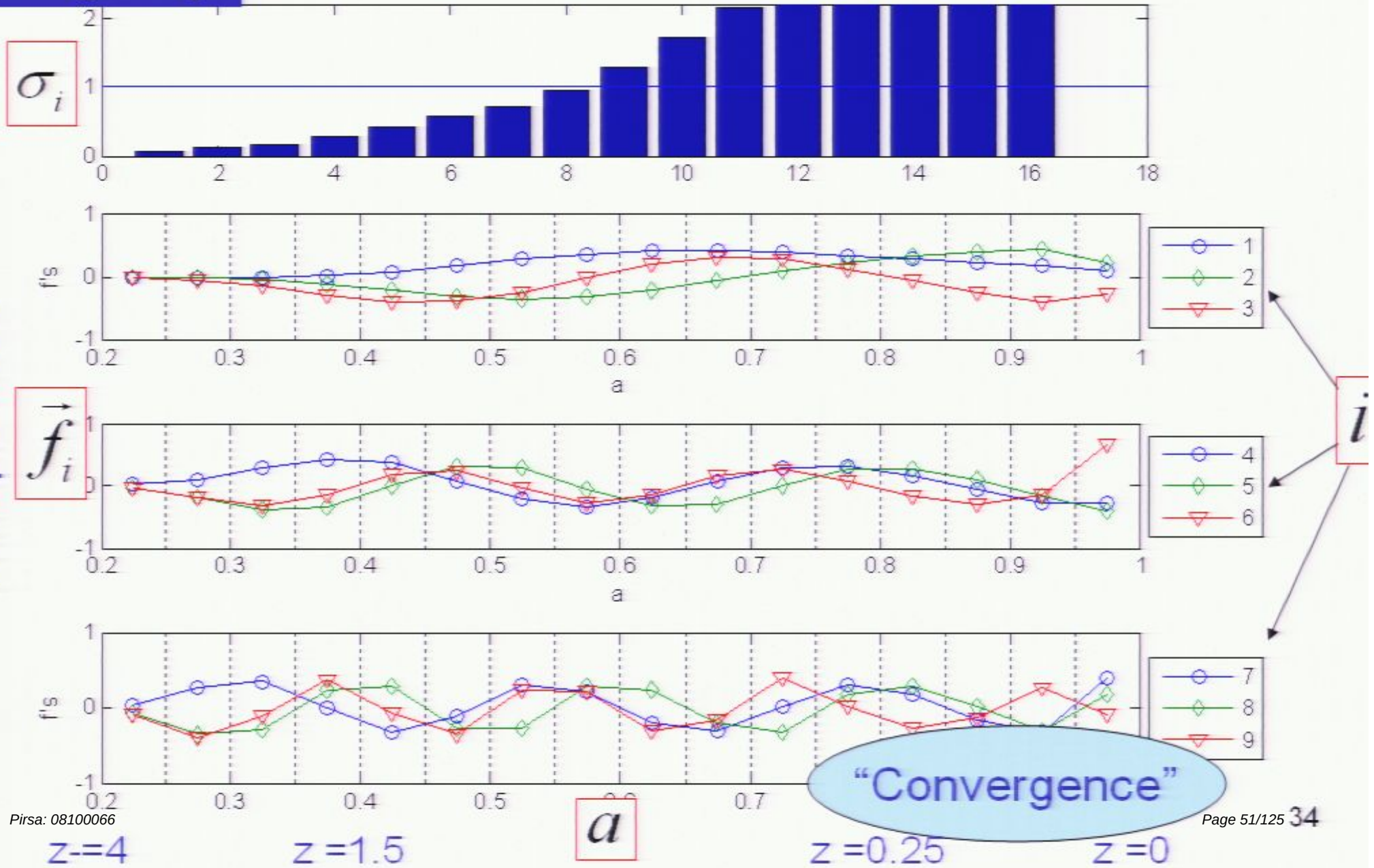
Characterizing 9D ellipses by principle axes and corresponding errors

VL Stage 4 Opt



Characterizing 9D ellipses by principle axes and corresponding errors

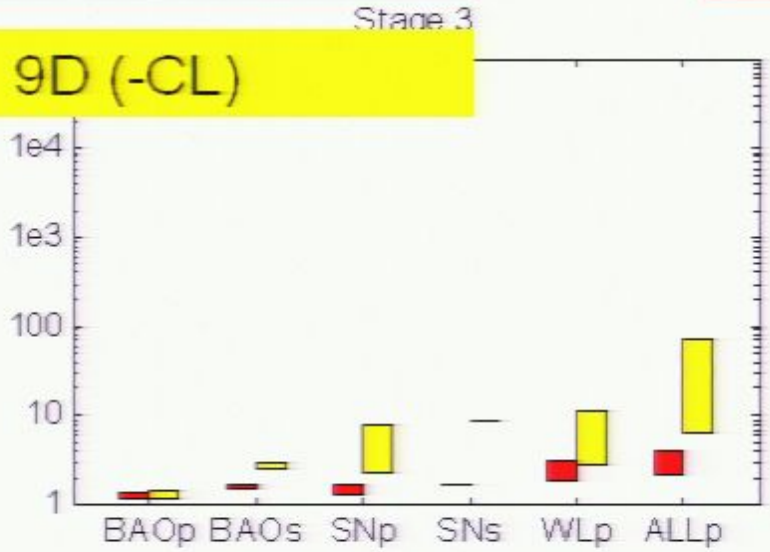
L Stage 4 Opt

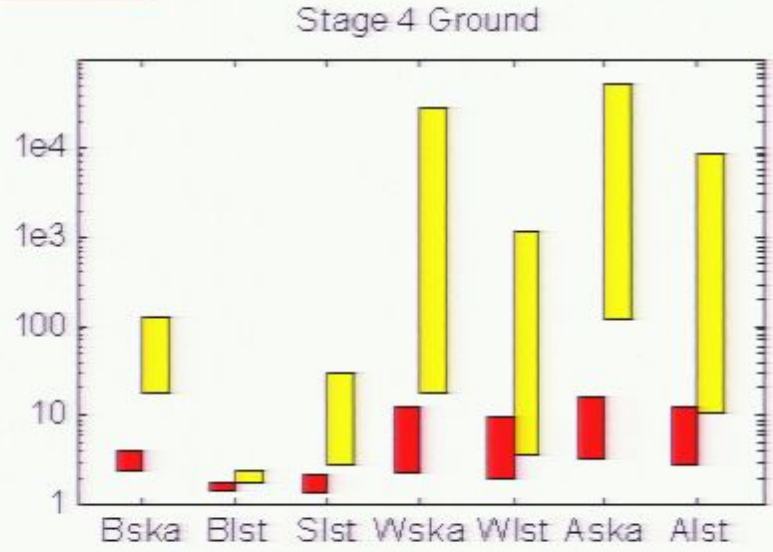


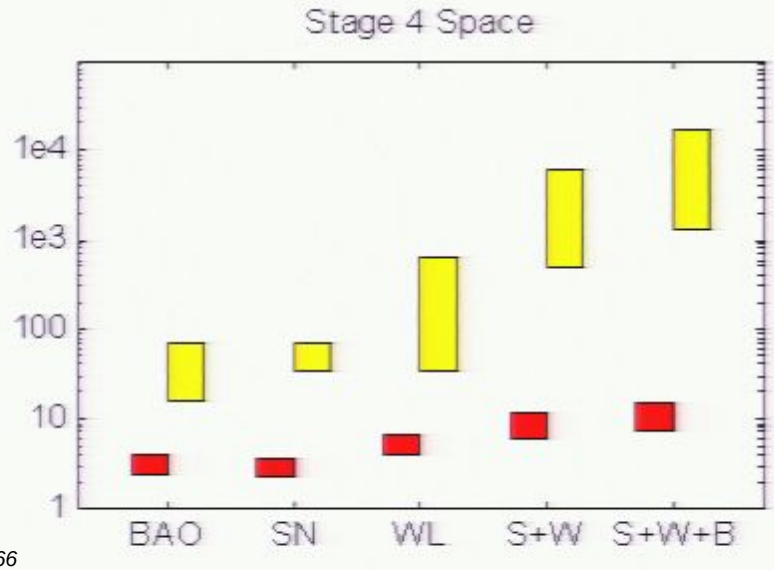
DETF(-CL)

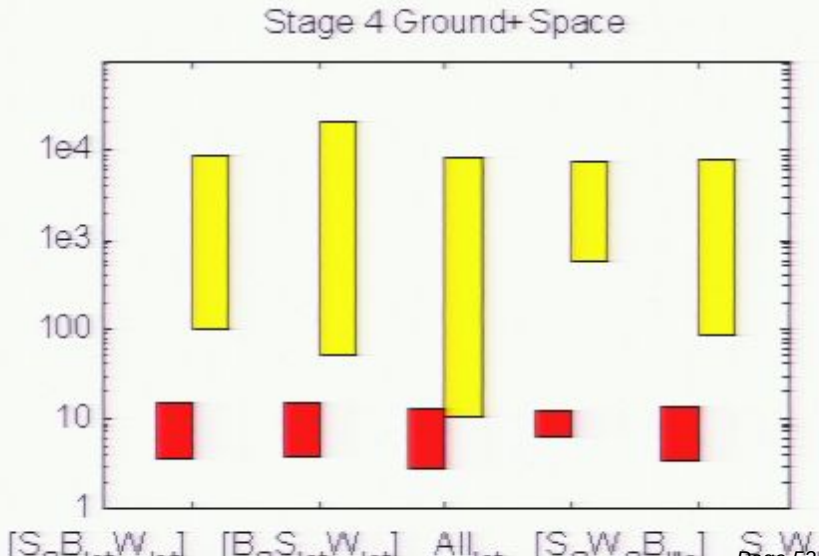
9D (-CL)

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









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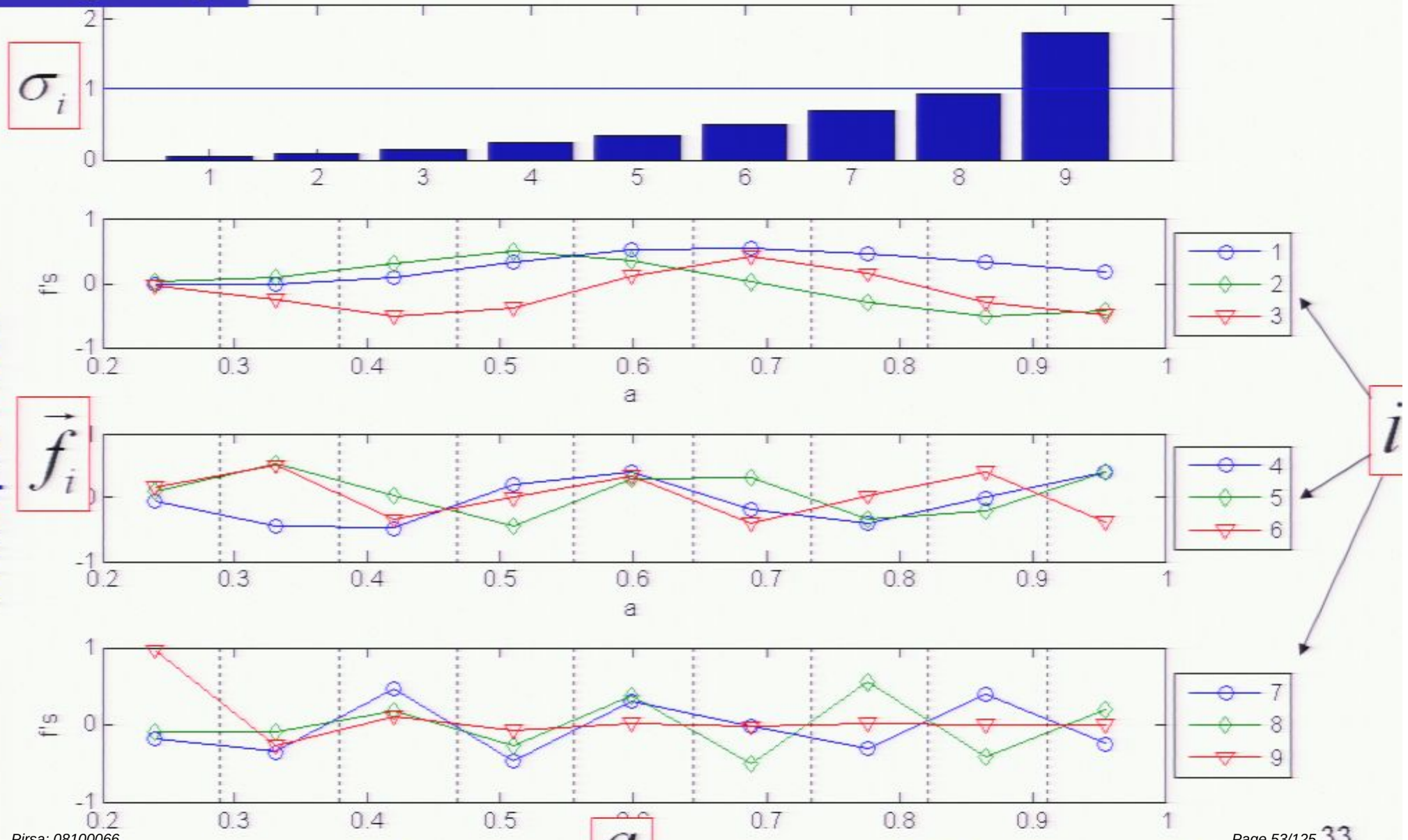


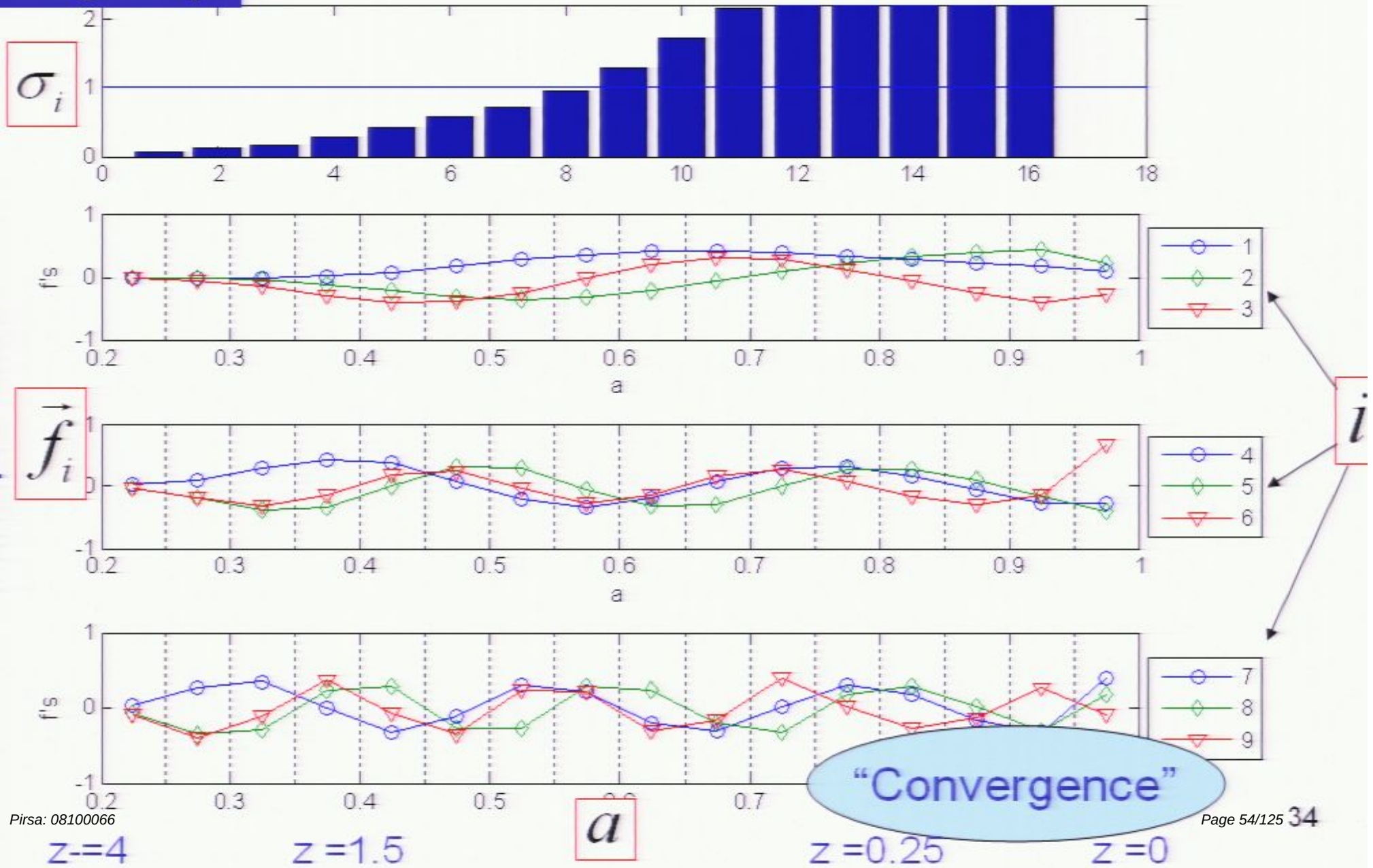
Ellipse

a

z-=4 z =1.5 z =0.25 z =0

Characterizing 9D ellipses by principle axes and corresponding errors

VL Stage 4 Opt



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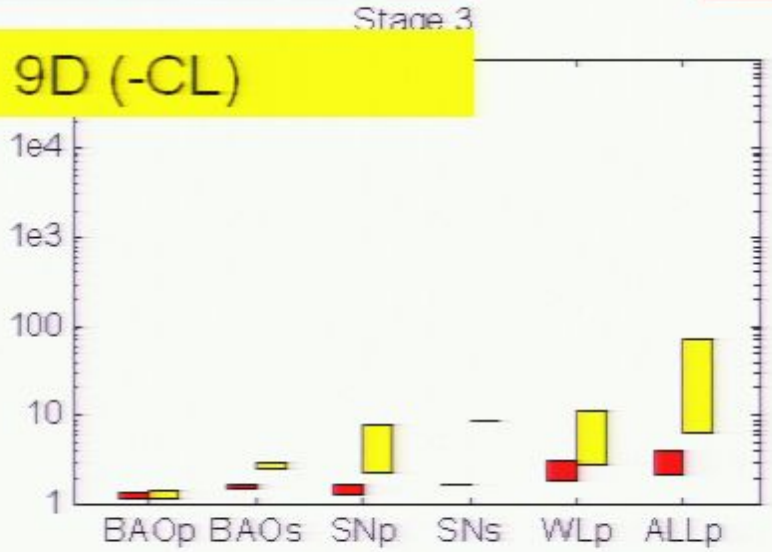

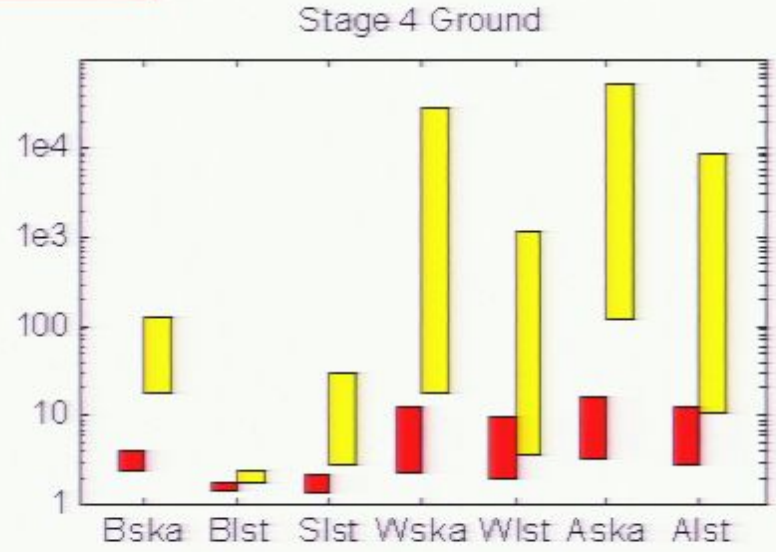

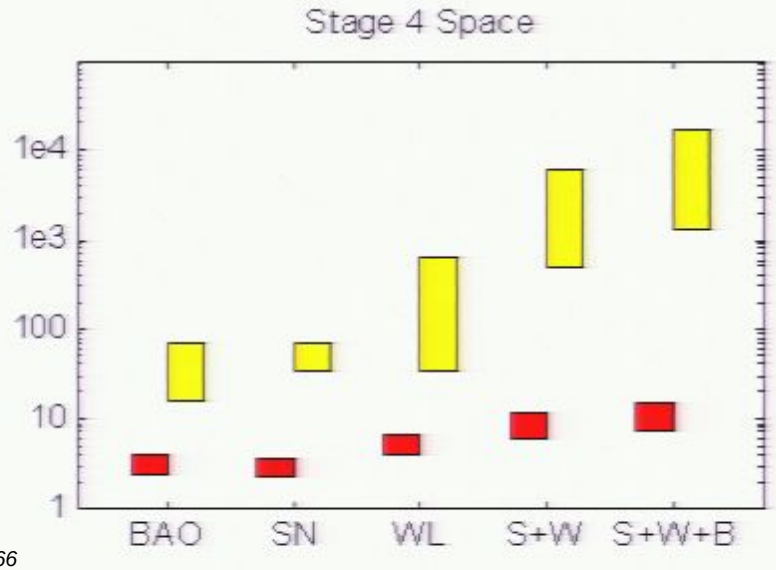

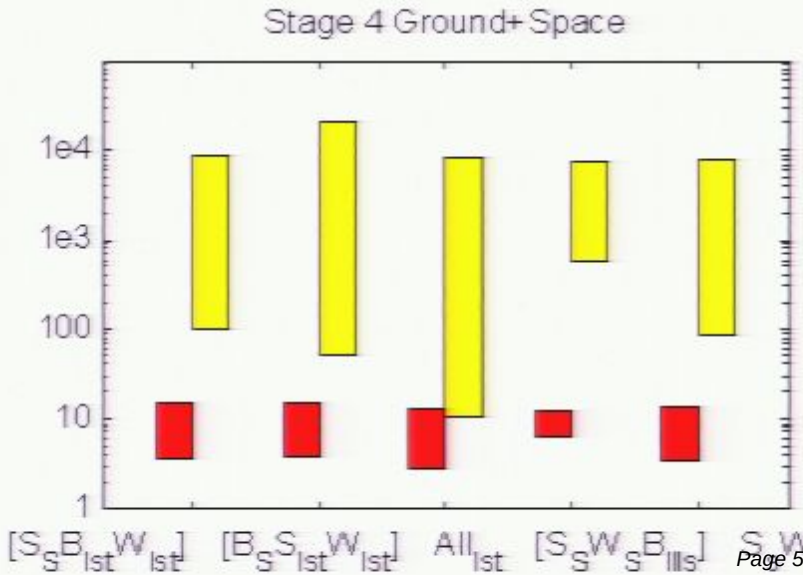

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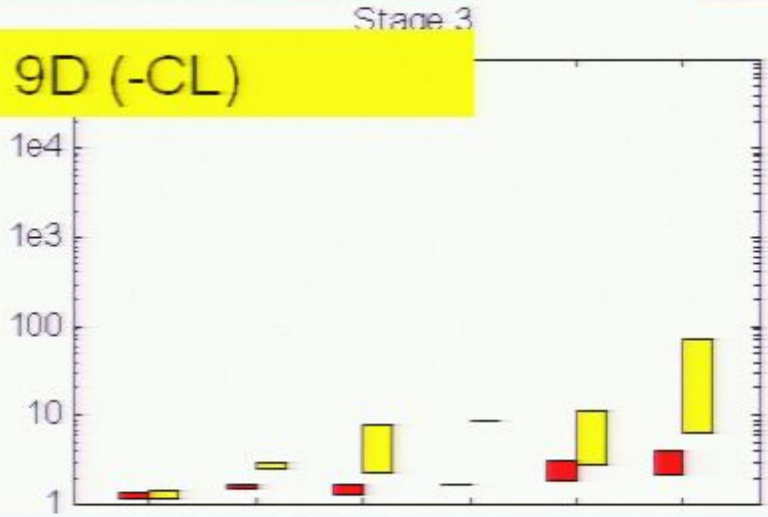
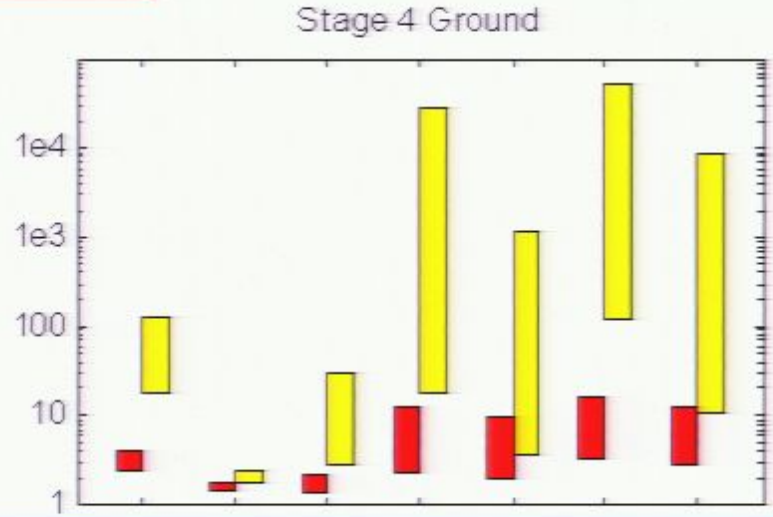
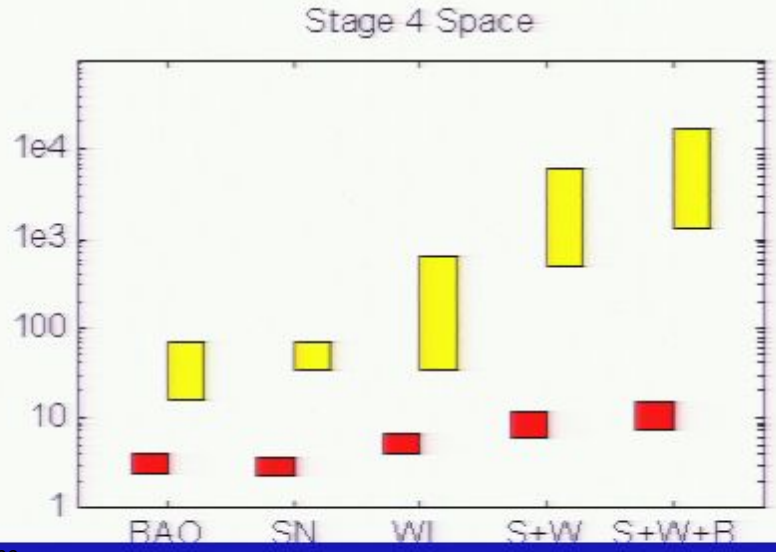
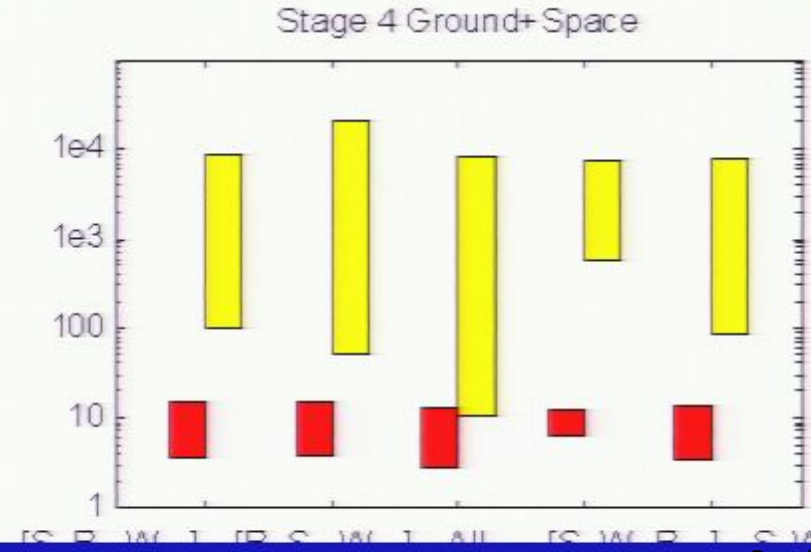




Stage 2 ➔ Stage 3 = 1 order of magnitude (vs 0.5 for DETF)





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

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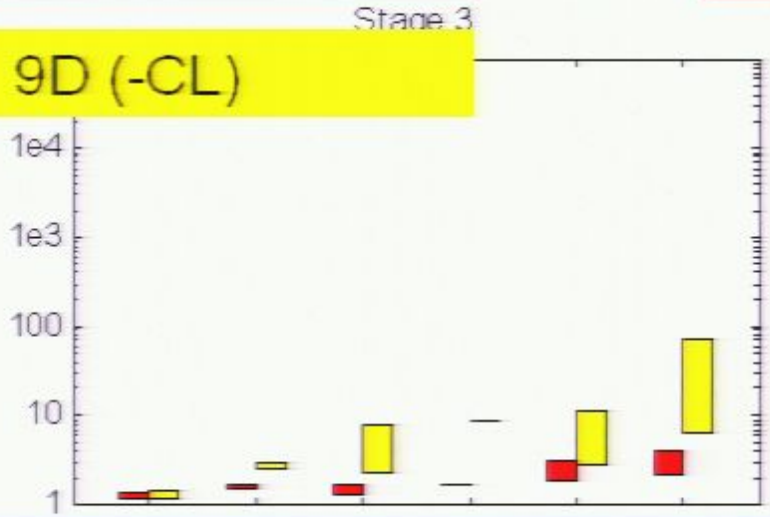

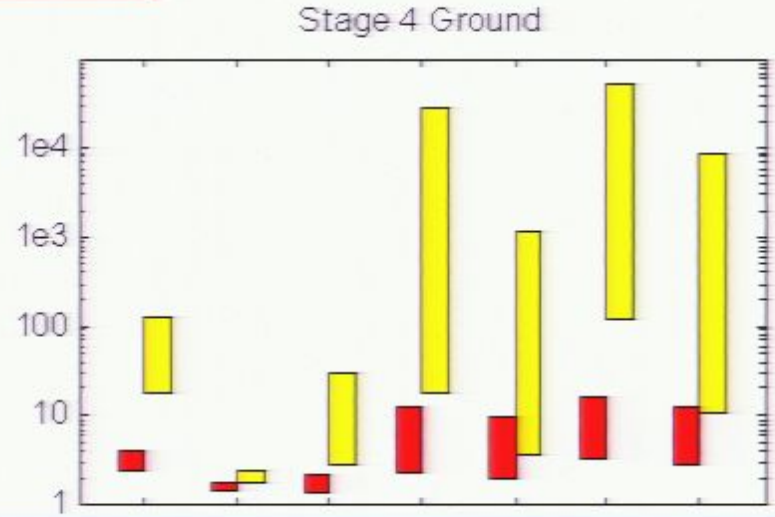

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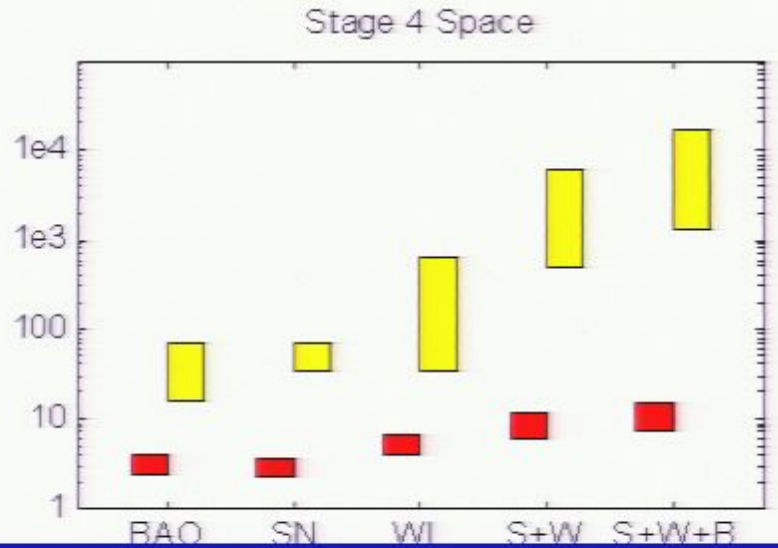

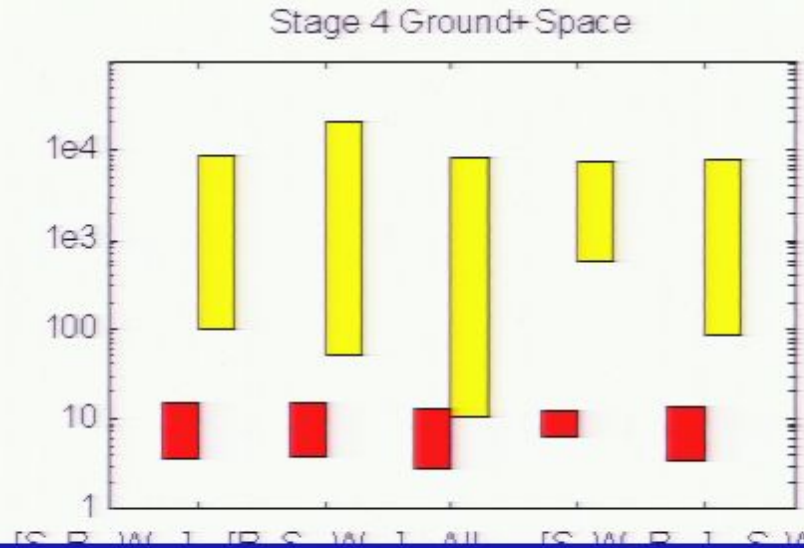

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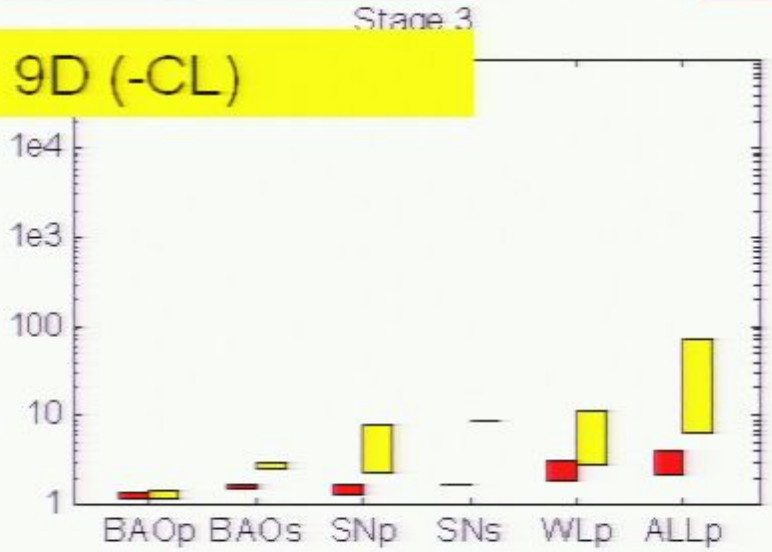
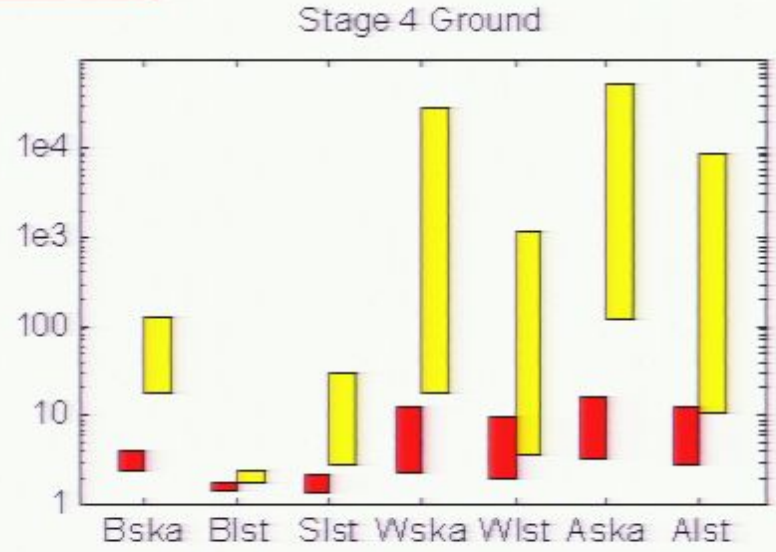
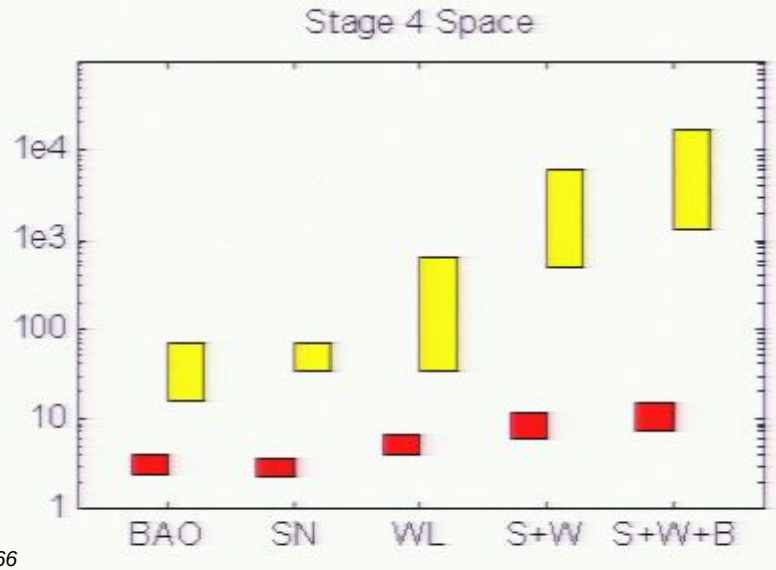
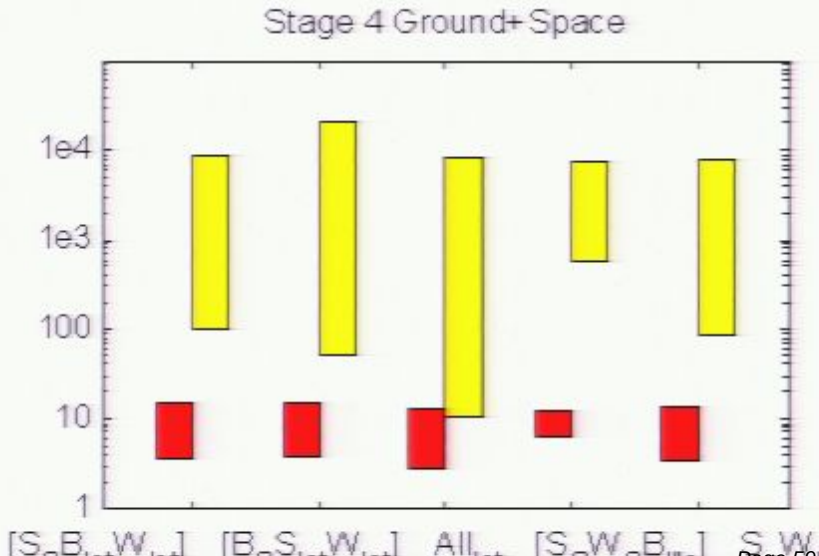
9D (-CL)

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









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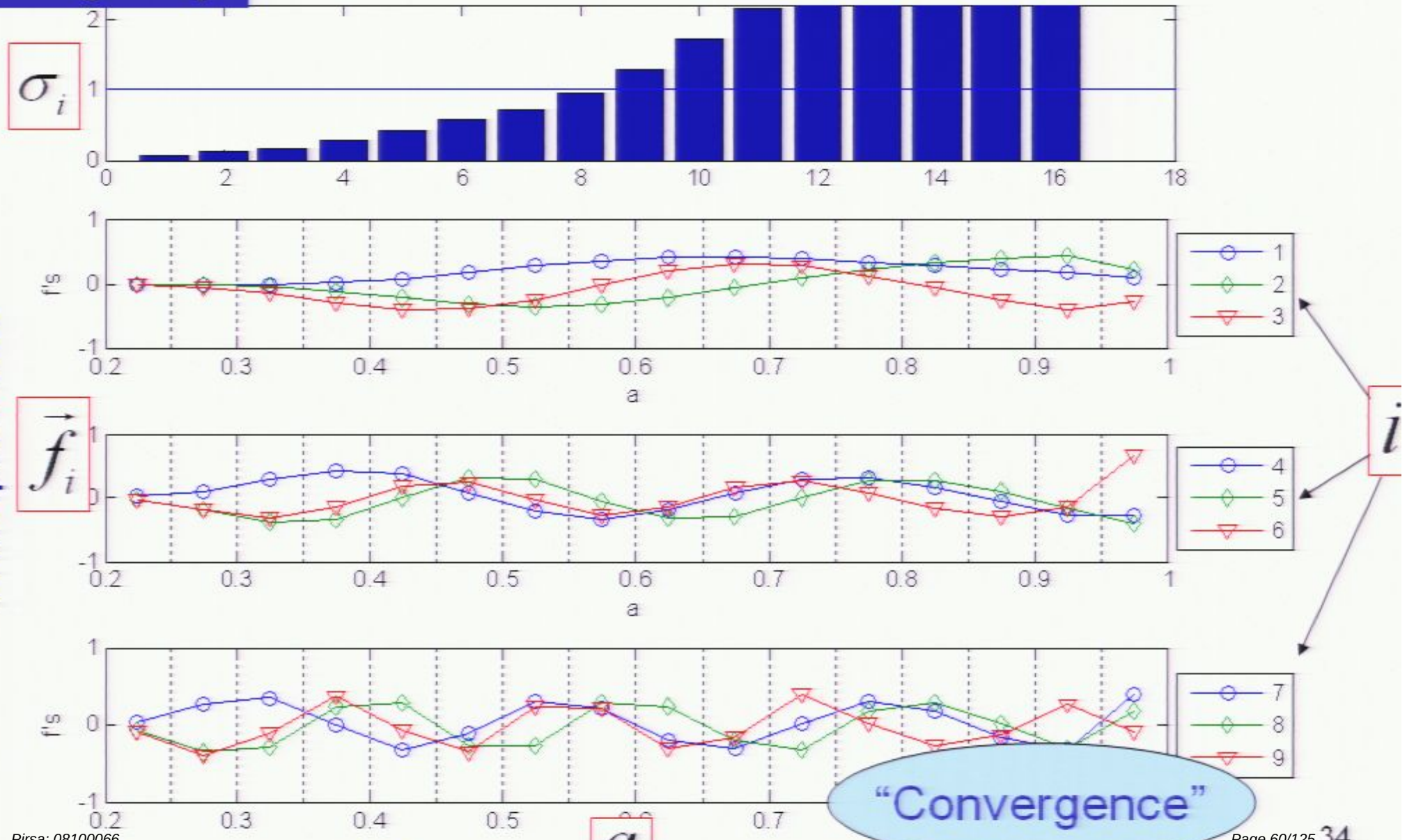
VL Stage 4 Opt



Upshot of 9D FoM:

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Inverts cost/FoM Estimates S3 vs S4

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➔ A nice way to gain insights into data (real or imagined)

Followup questions:

→ In what ways might the choice of DE parameters have skewed the DETF results?

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→ To what extent can these data sets deliver discriminating power between specific DE models?

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A: Only by an overall (possibly important) rescaling

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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

Mark Yashar

+AA

+

DETF Simulated data

+

Quintessence potentials

+

MCMC

See also Dutta & Sorbo 2006, Huterer and Turner 1999 & especially *Huterer and Peiris 2006*

The potentials

Exponential (Wetterich, Peebles & Ratra)

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

PNGB aka Axion (Frieman et al)

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

Exponential with prefactor (AA & Skordis)

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

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Stronger than average motivations & interest

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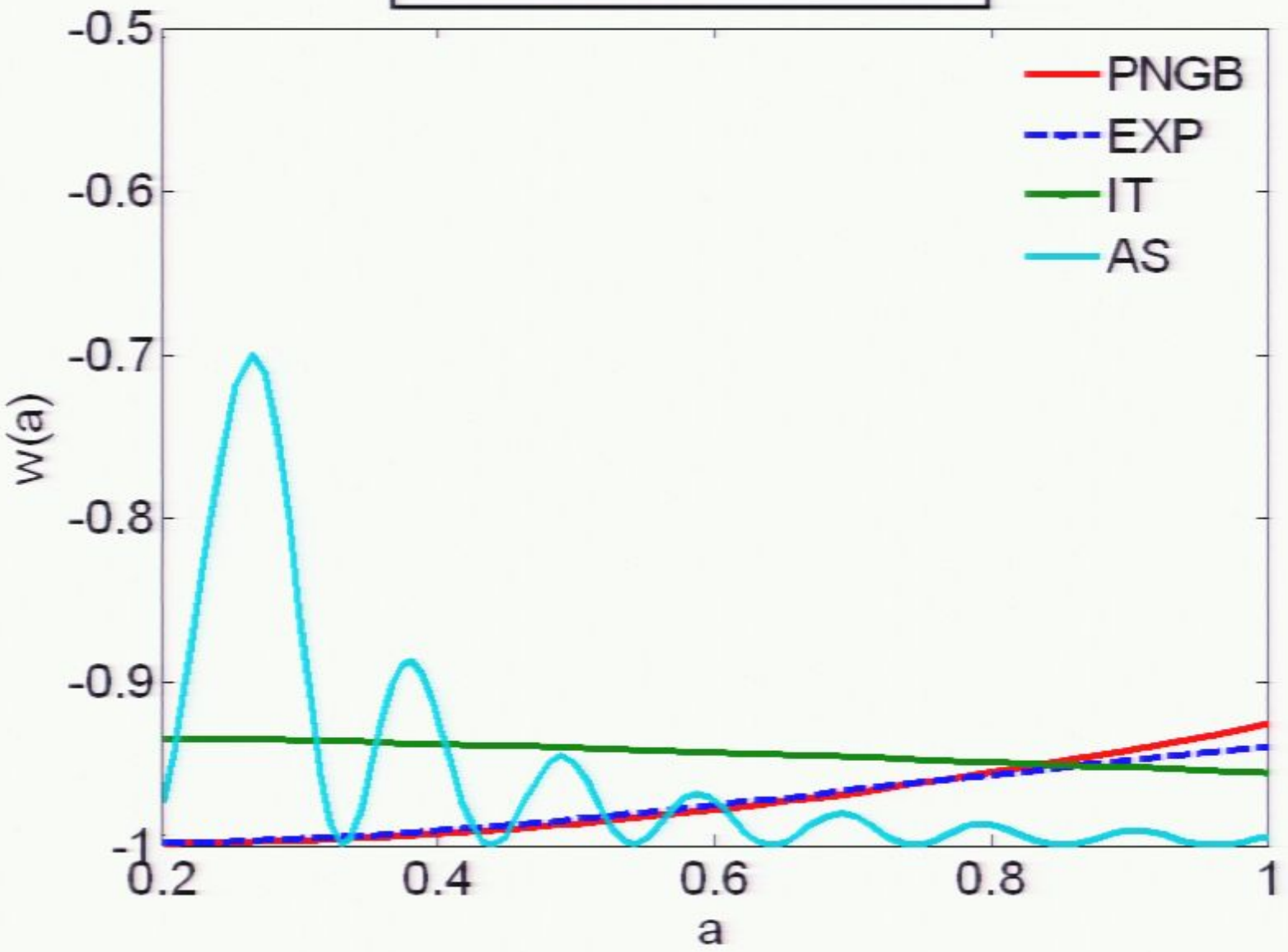
ArXiv Dec 08, PRD in press

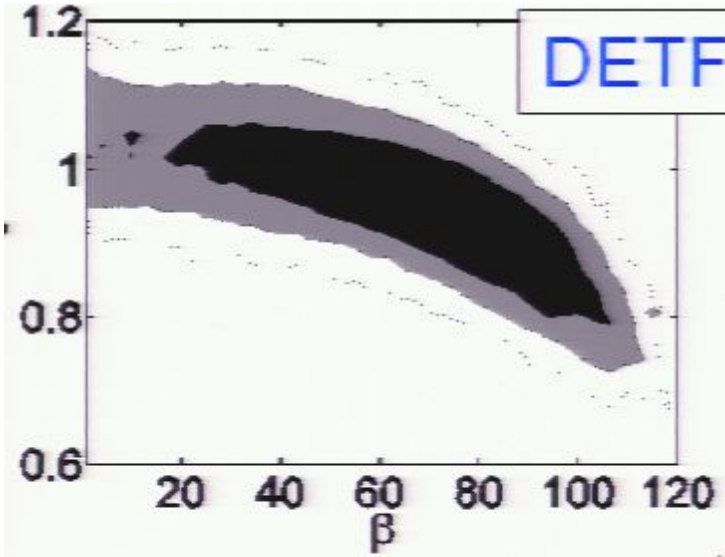
Inverse Tracker (Ratra & Peebles, Steinhardt et al)

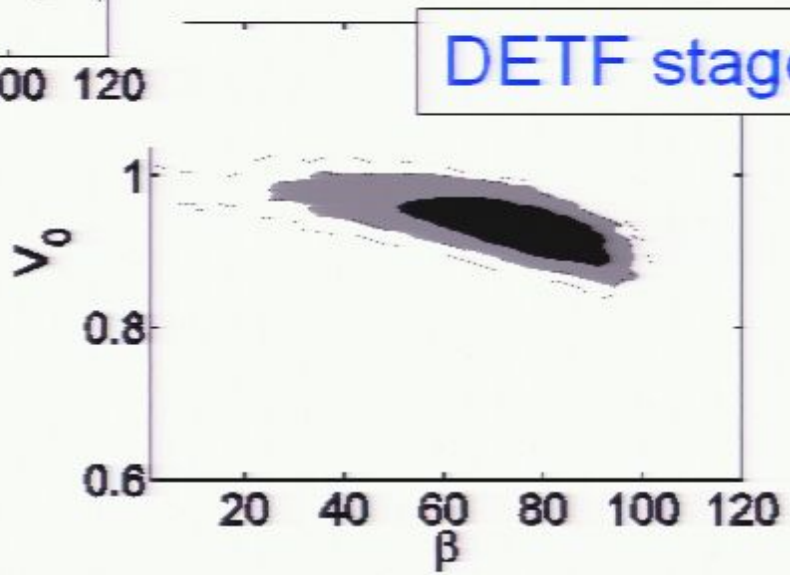
$$V(\varphi) = V_0\left(\frac{m}{\varphi}\right)^{\alpha}$$

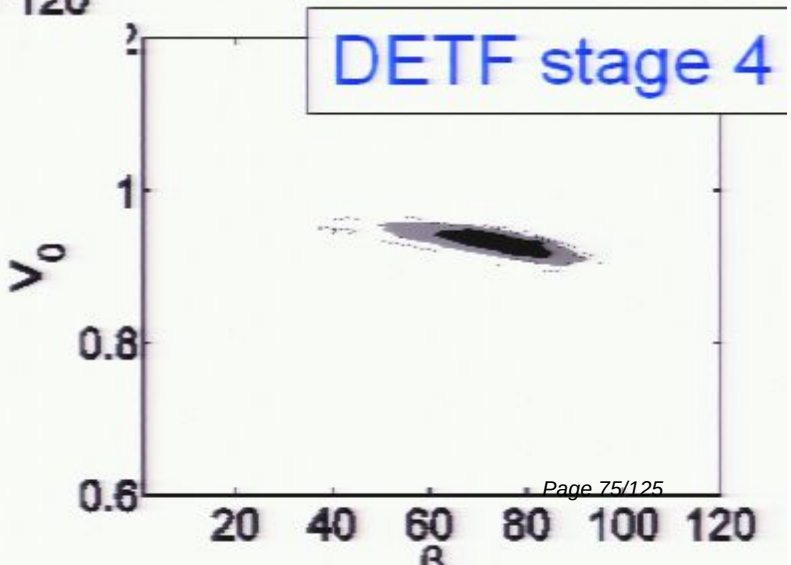
← In prep.

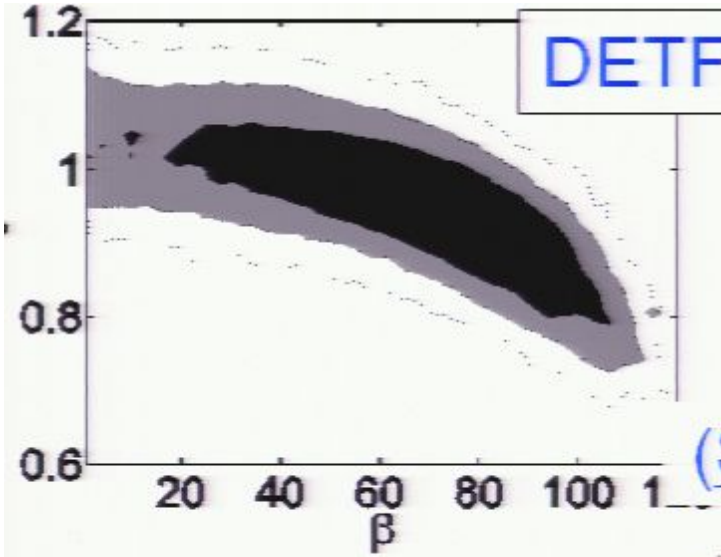
…they cover a variety of behavior.




DETF stage 2
1.2
1
0.8
0.6
20
40
60
80
100
120
β


DETF stage 3
1
0.8
0.6
v_o
20
40
60
80
100
120
β

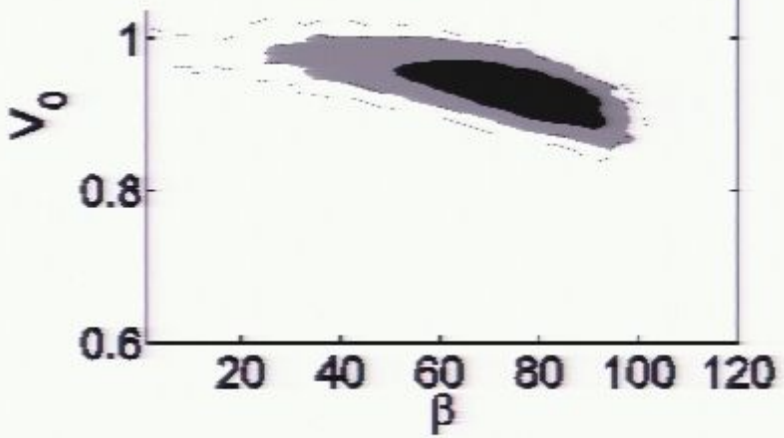

DETF stage 4
1
0.8
0.6
v_o
20
40
60
80
100
120



DETF stage 2

(S2/3)

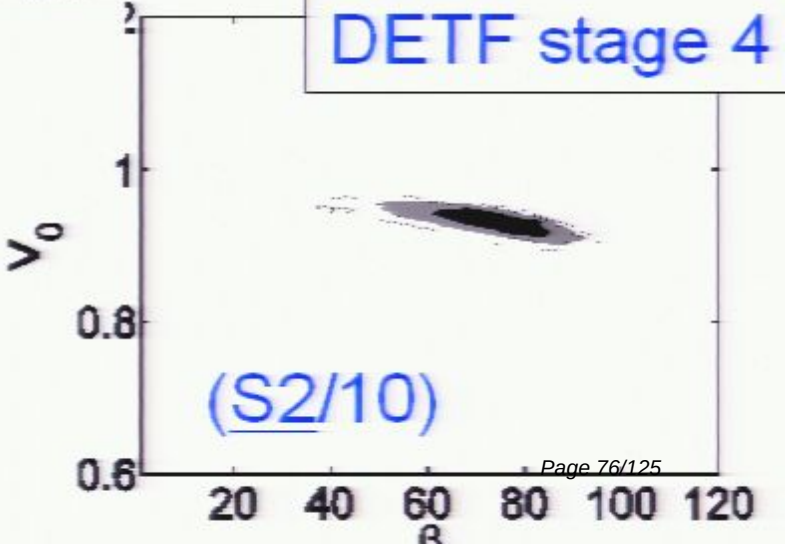
DETF stage 3



Upshot:

Story in scalar field parameter space very similar to DETF story in w0-wa space.

DETF stage 4



(S2/10)

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A: Very similar to DETF results in w0-wa space

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Michael Barnard *et al* ***arXiv:0804.0413***

Problem:

Each scalar field model is defined in its own parameter space. How should one quantify discriminating power among models?

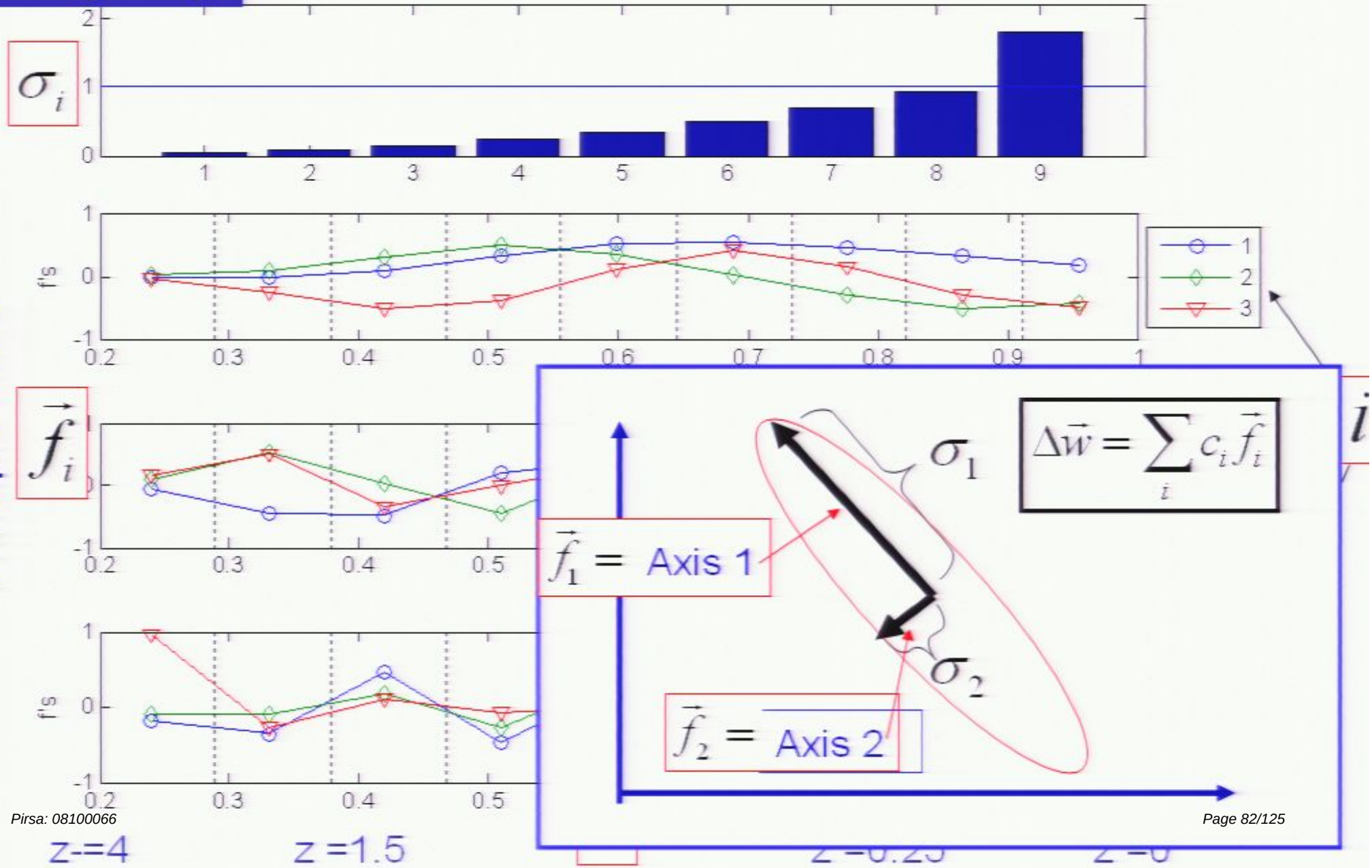
Our answer:

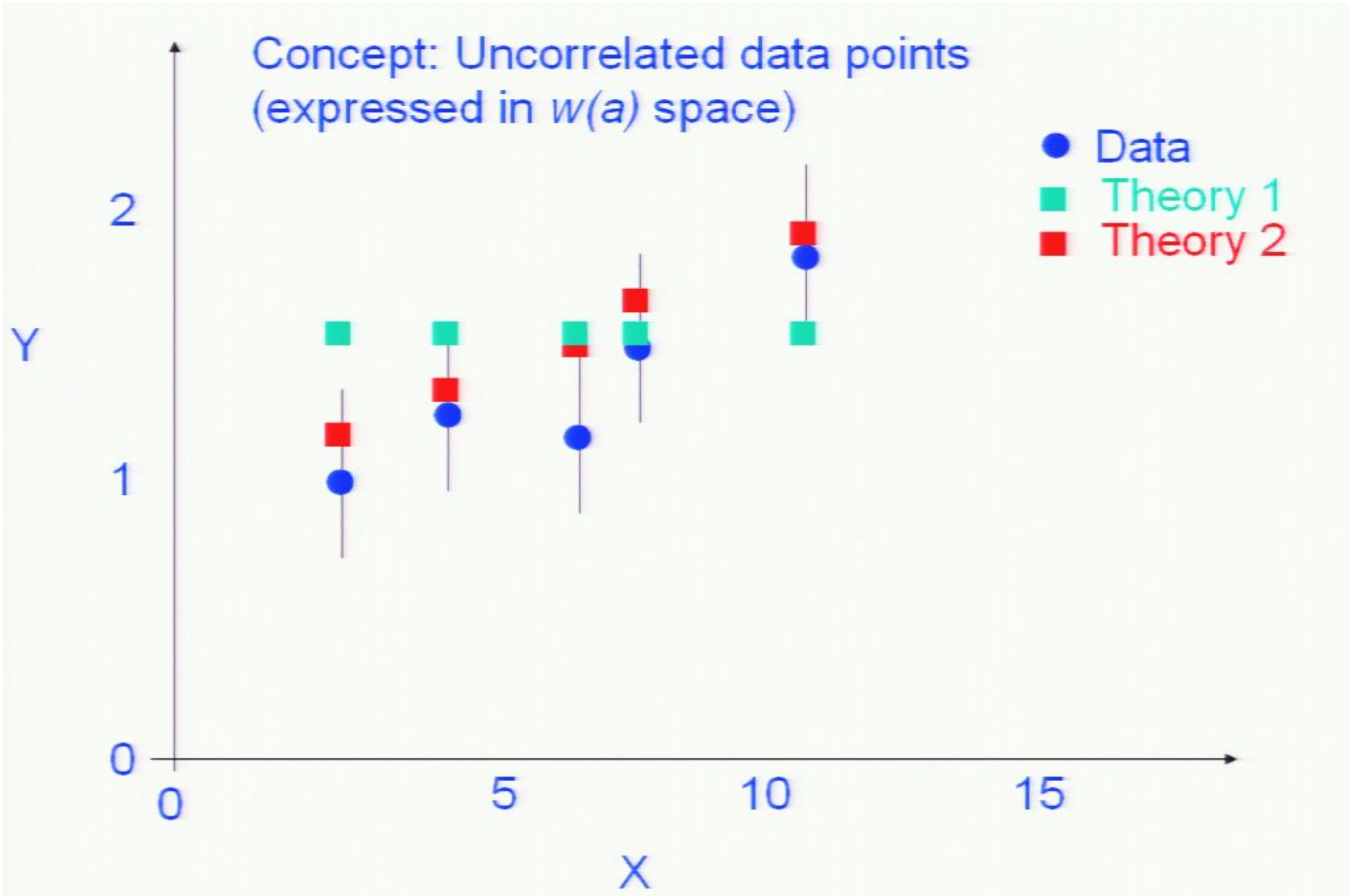
➔Form each set of scalar field model parameter values, map the solution into *w(a)* eigenmode space, the space of uncorrelated observables.

➔ Make the comparison in the space of uncorrelated observables.

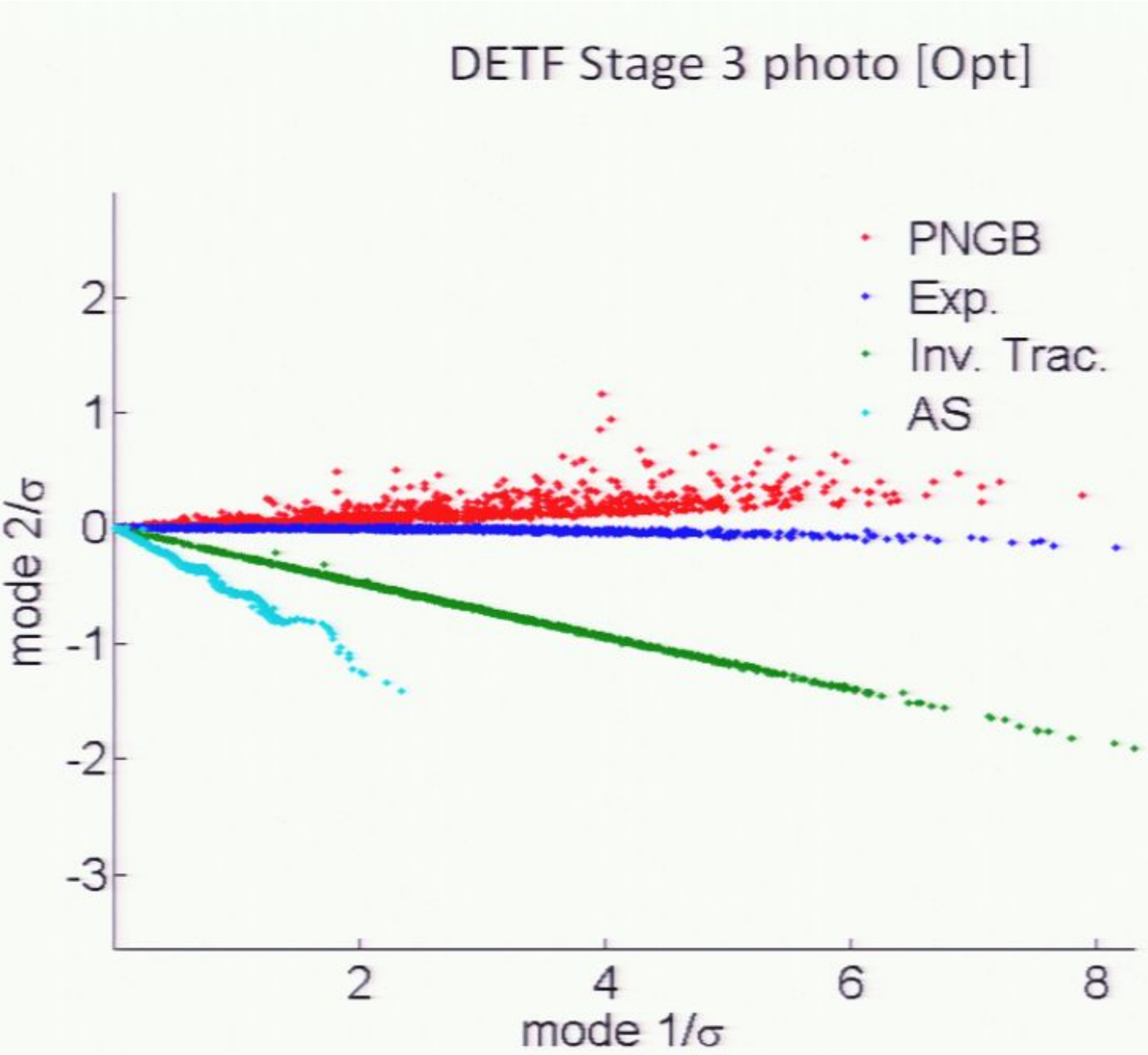
Characterizing 9D ellipses by principle axes and corresponding errors

L Stage 4 Opt



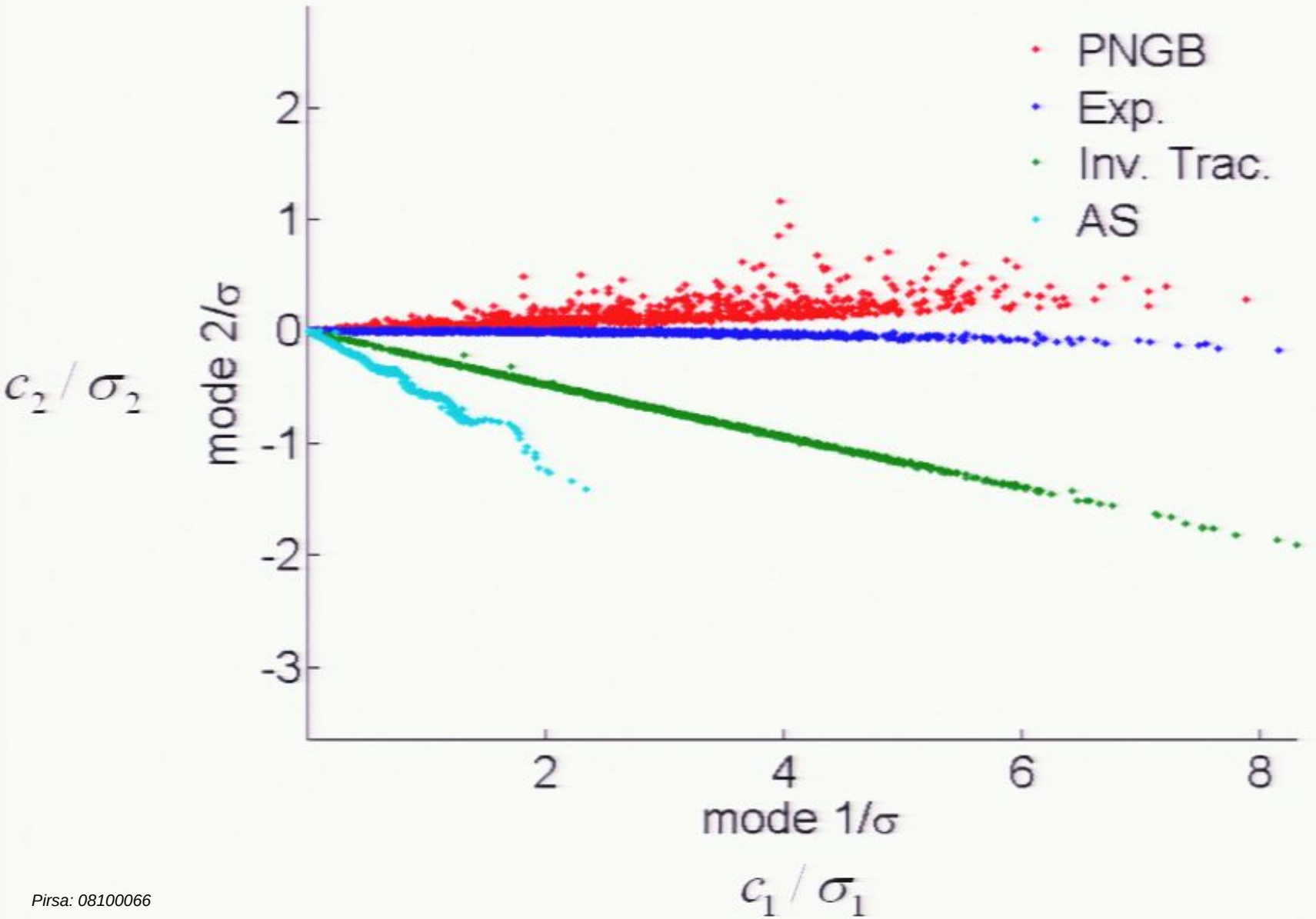

Concept: Uncorrelated data points
(expressed in w(a) space)
Data
Theory 1
Theory 2
Y
2
1
0
0
5
10
15
X

Starting point: MCMC chains giving distributions for each model at Stage 2.

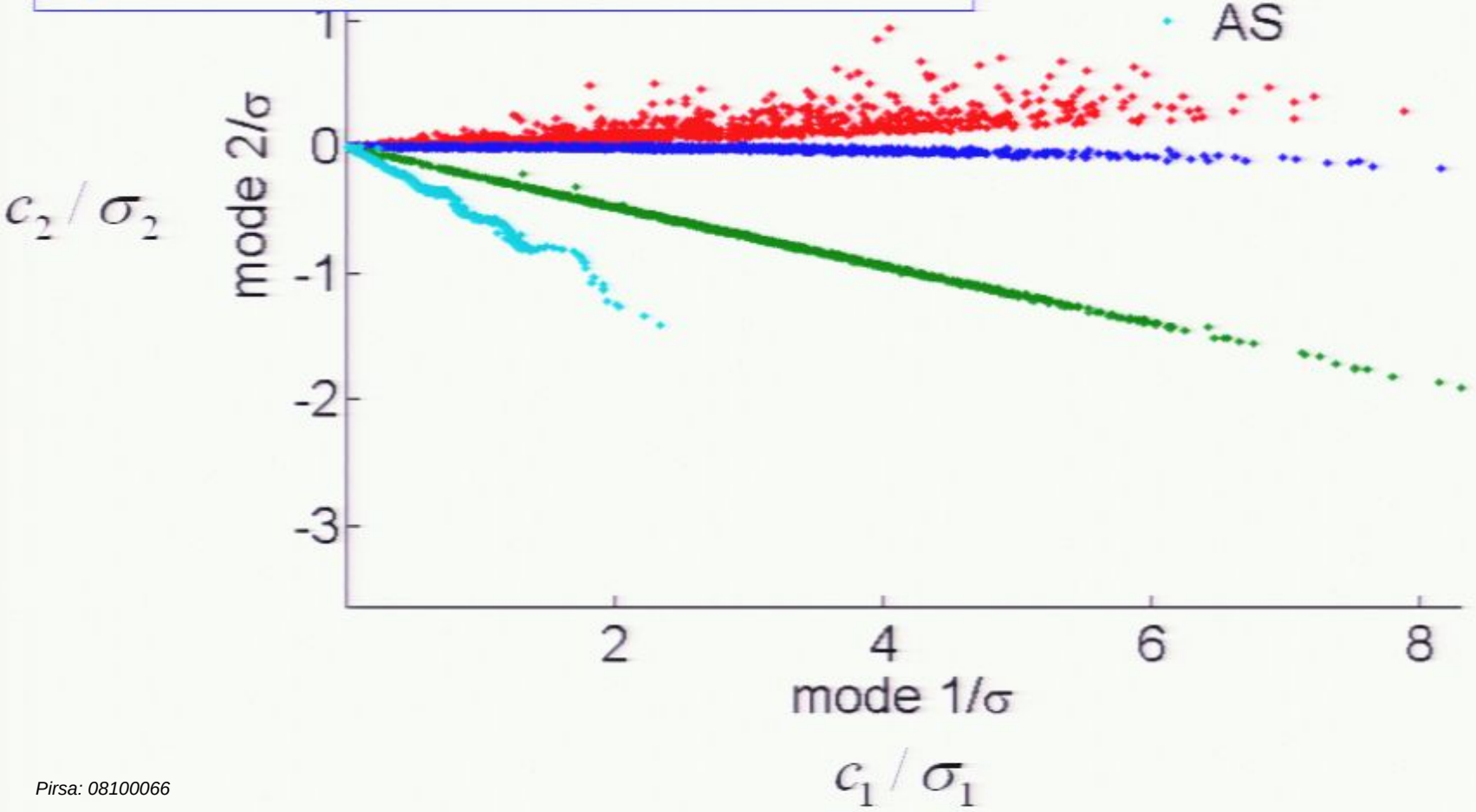

DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
2
1
0
-1
-2
-3
2
4
6
8

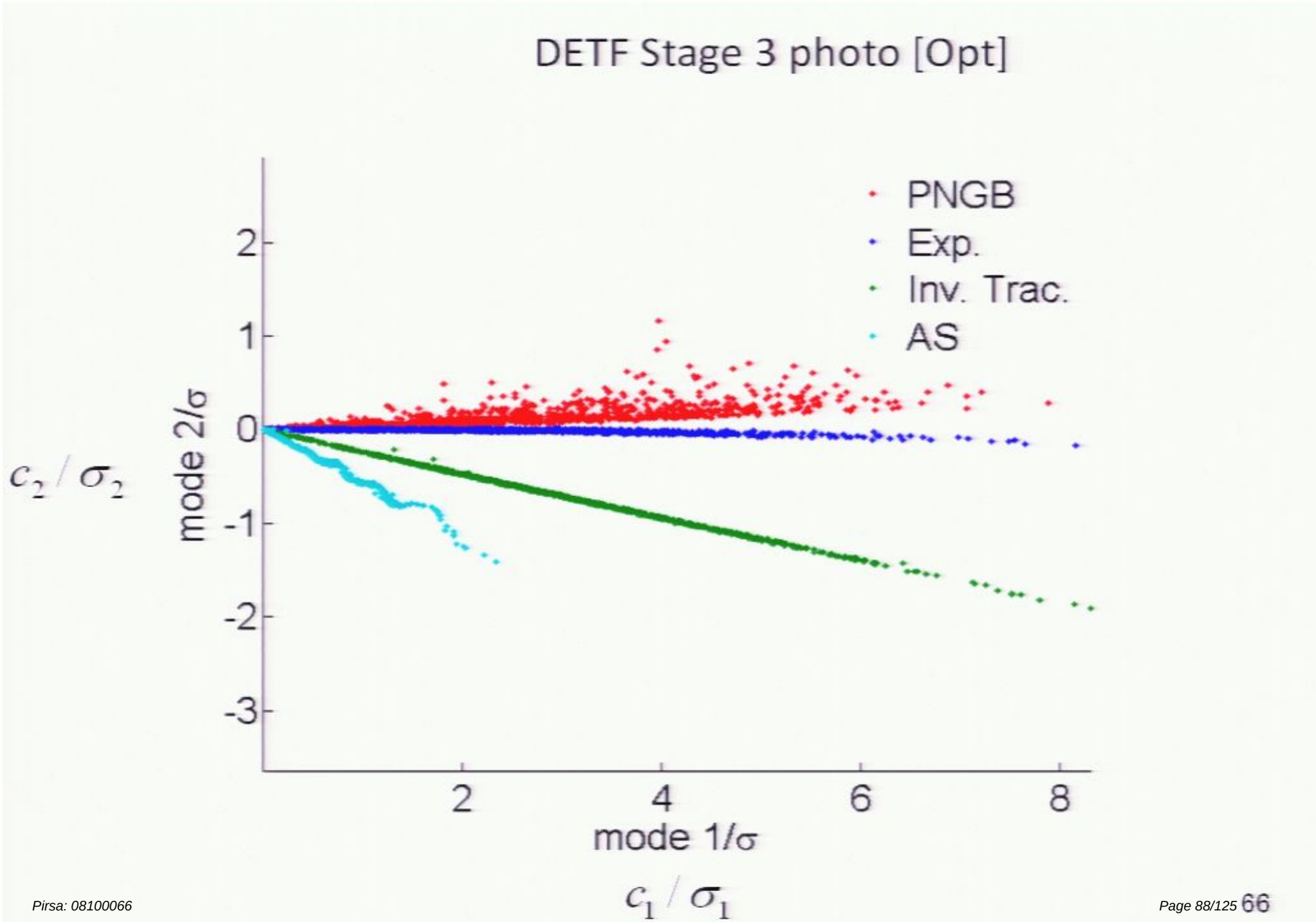
$$\Delta\vec{w} = \sum_i c_i \vec{f}_i$$

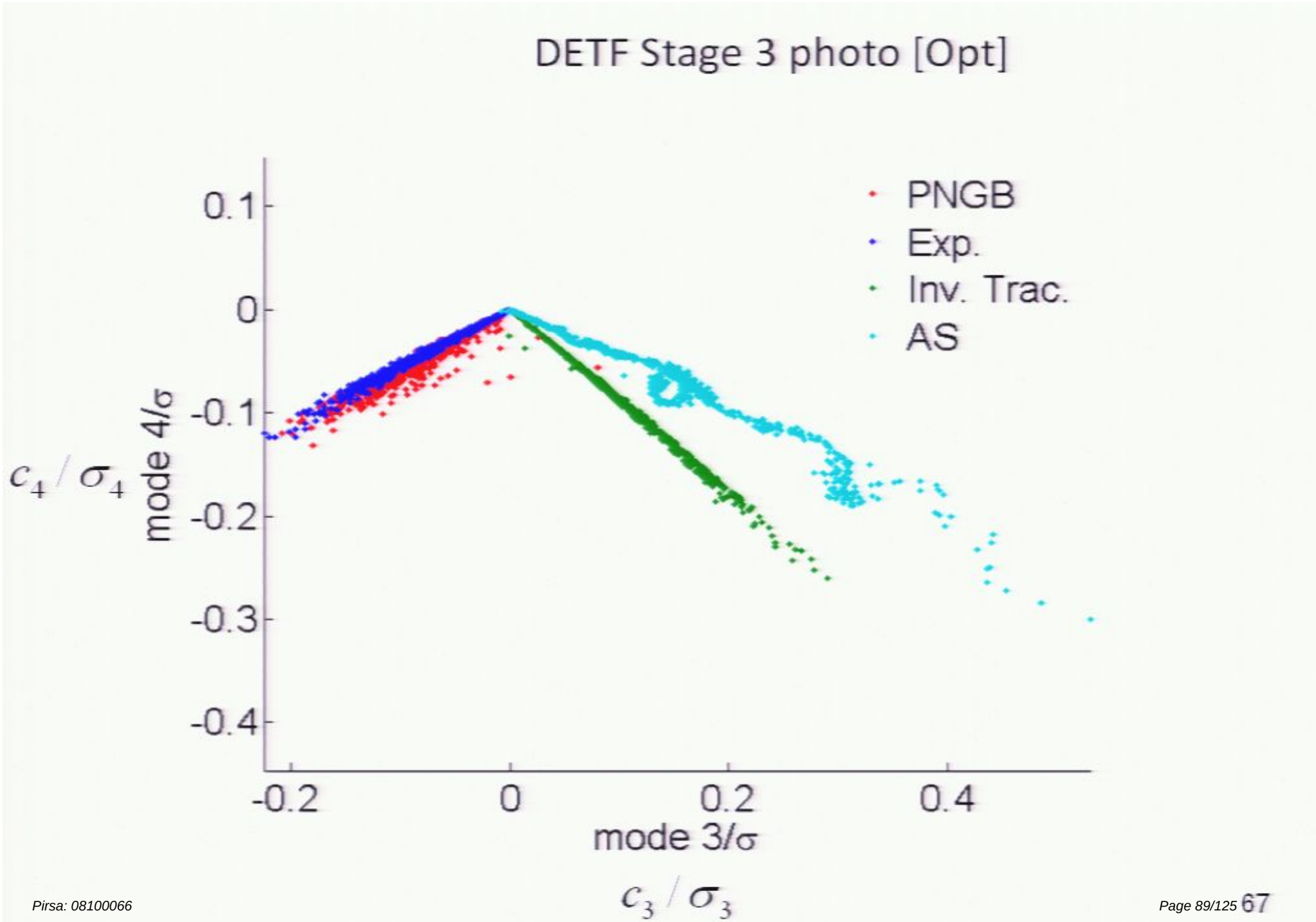
DETF Stage 3 photo [Opt]

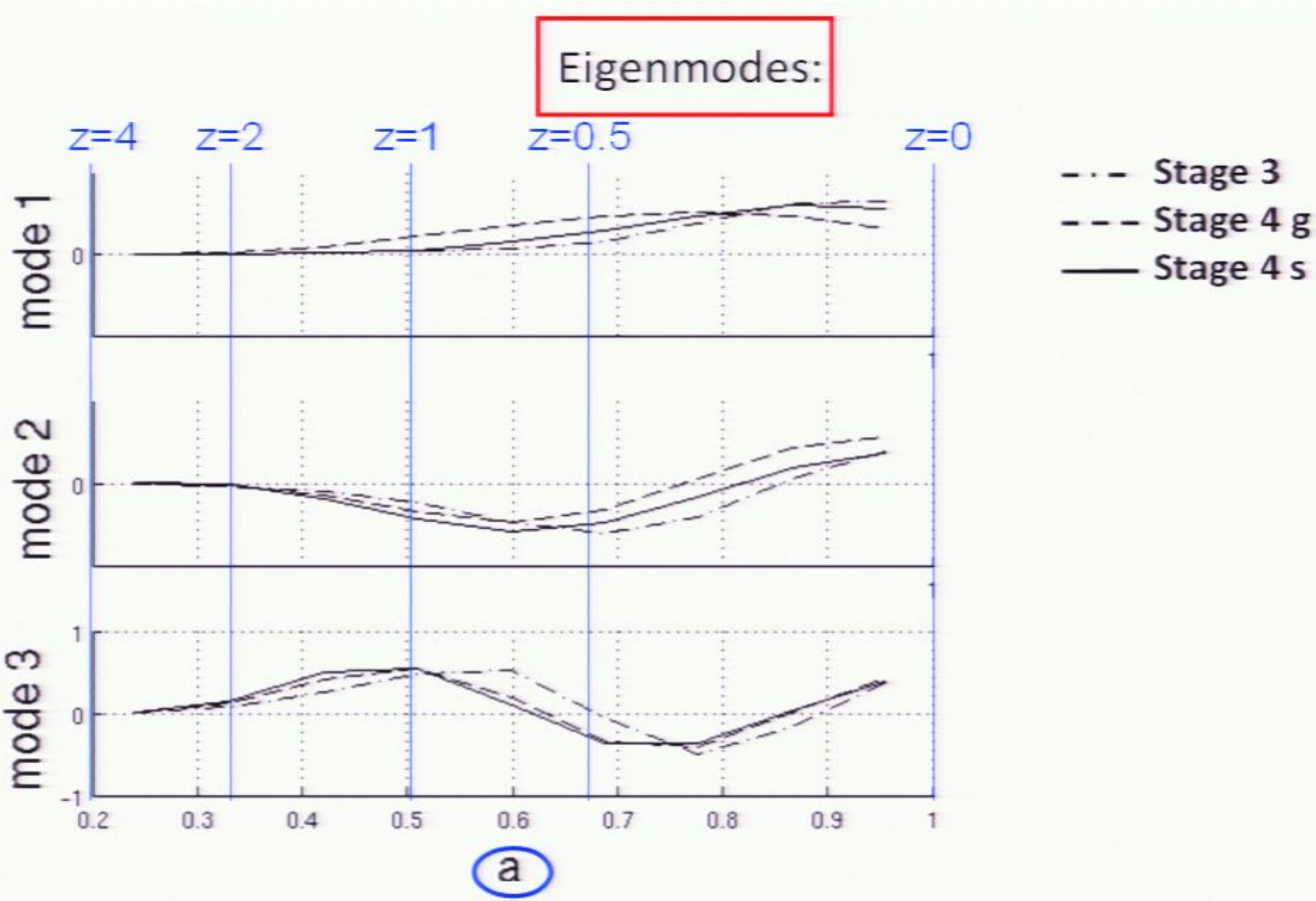


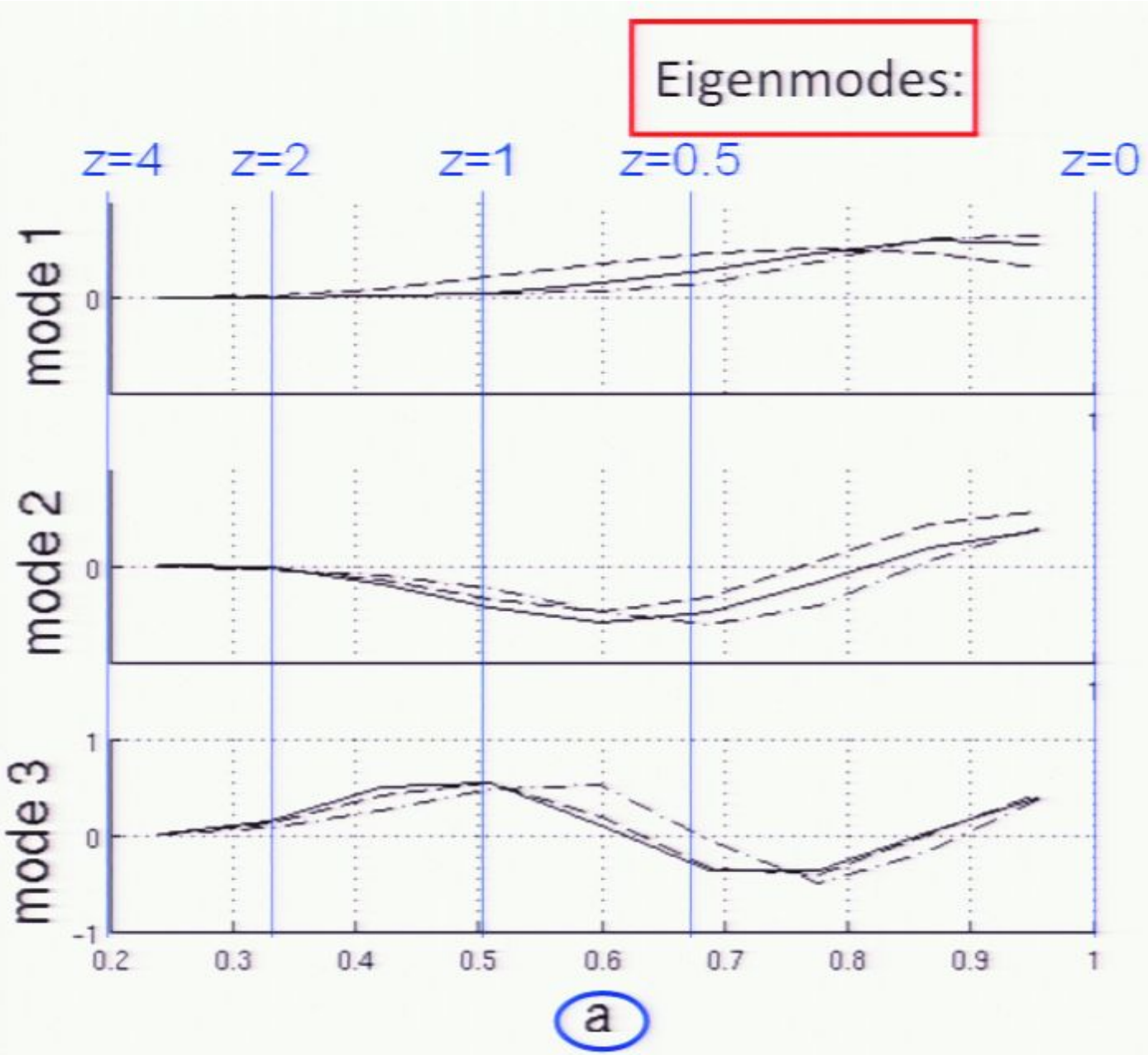
- Distinct model locations
- mode amplitude/σ_i "physical"
- Modes (and σ_i's) reflect specific expts.




DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
c_2 / σ_2
c_1 / σ_1
2
1
0
-1
-2
-3
2
4
6
8


DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
0.1
0
-0.1
-0.2
-0.3
-0.4
mode 4/σ
c_4 / σ_4
-0.2
0
0.2
0.4
mode 3/σ
c_3 / σ_3


Eigenmodes:
z=4
z=2
z=1
z=0.5
z=0
mode 1
mode 2
mode 3
0
0
1
0
-1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
a
Stage 3
Stage 4 g
Stage 4 s

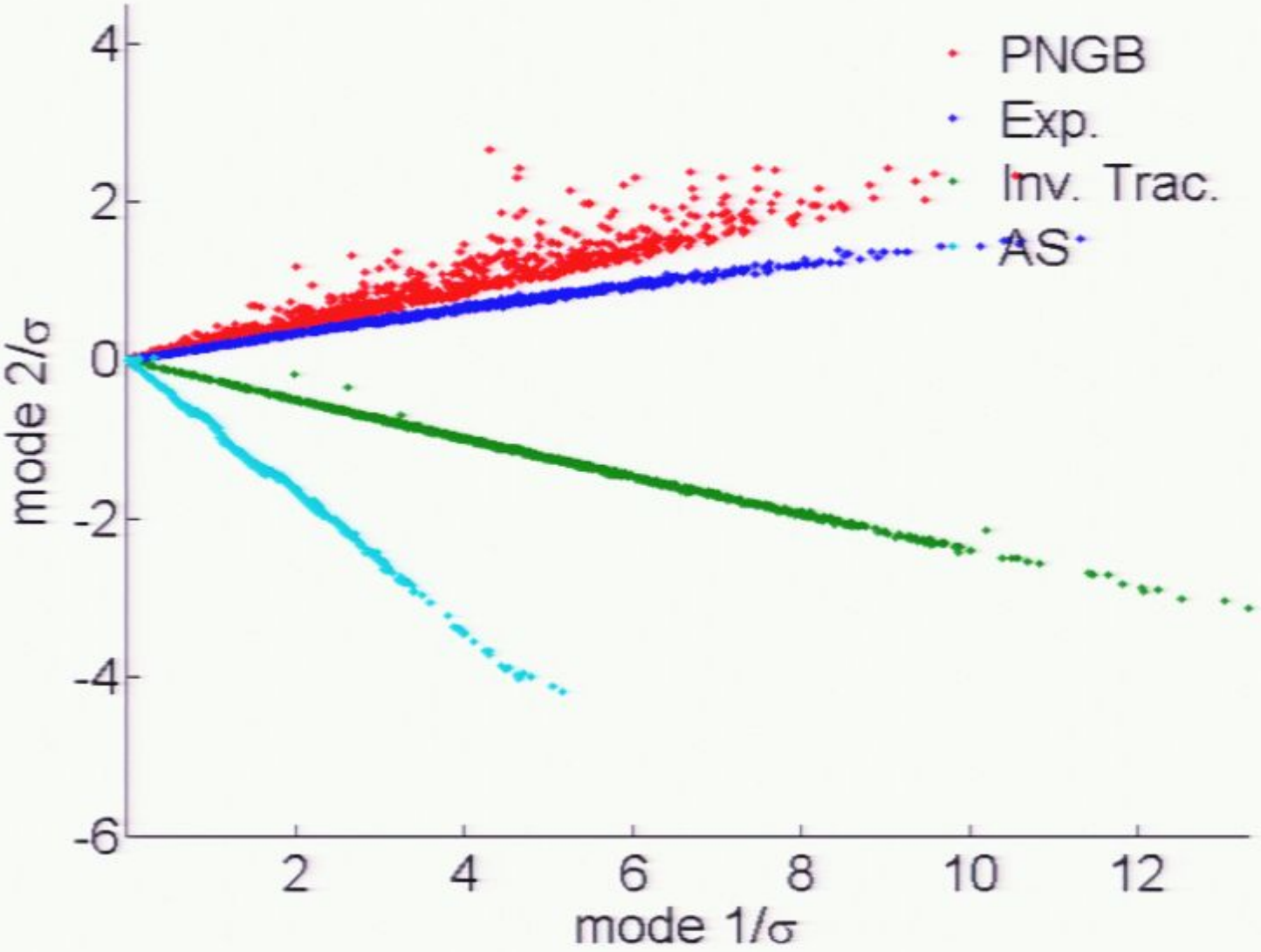


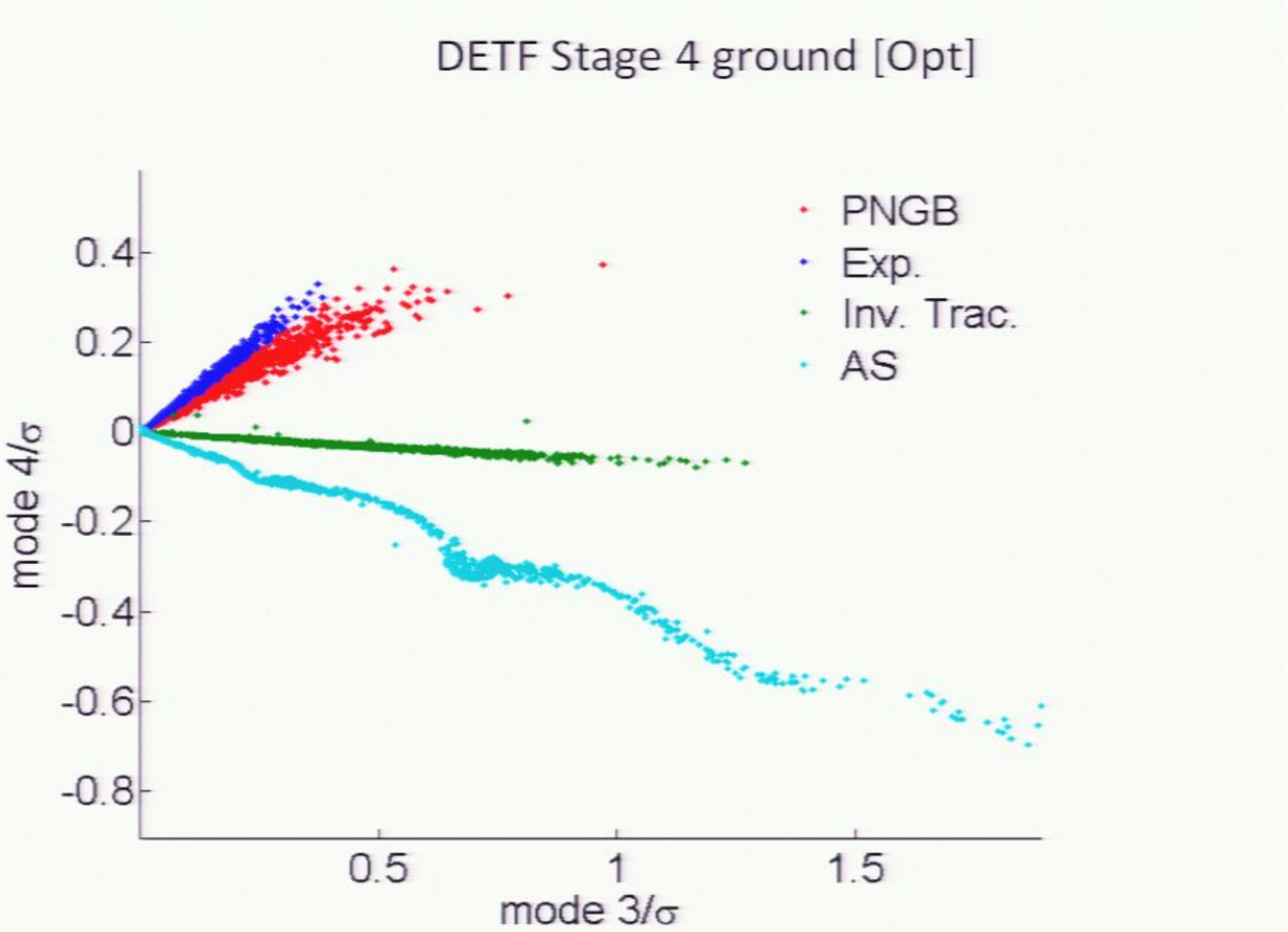
Stage 3

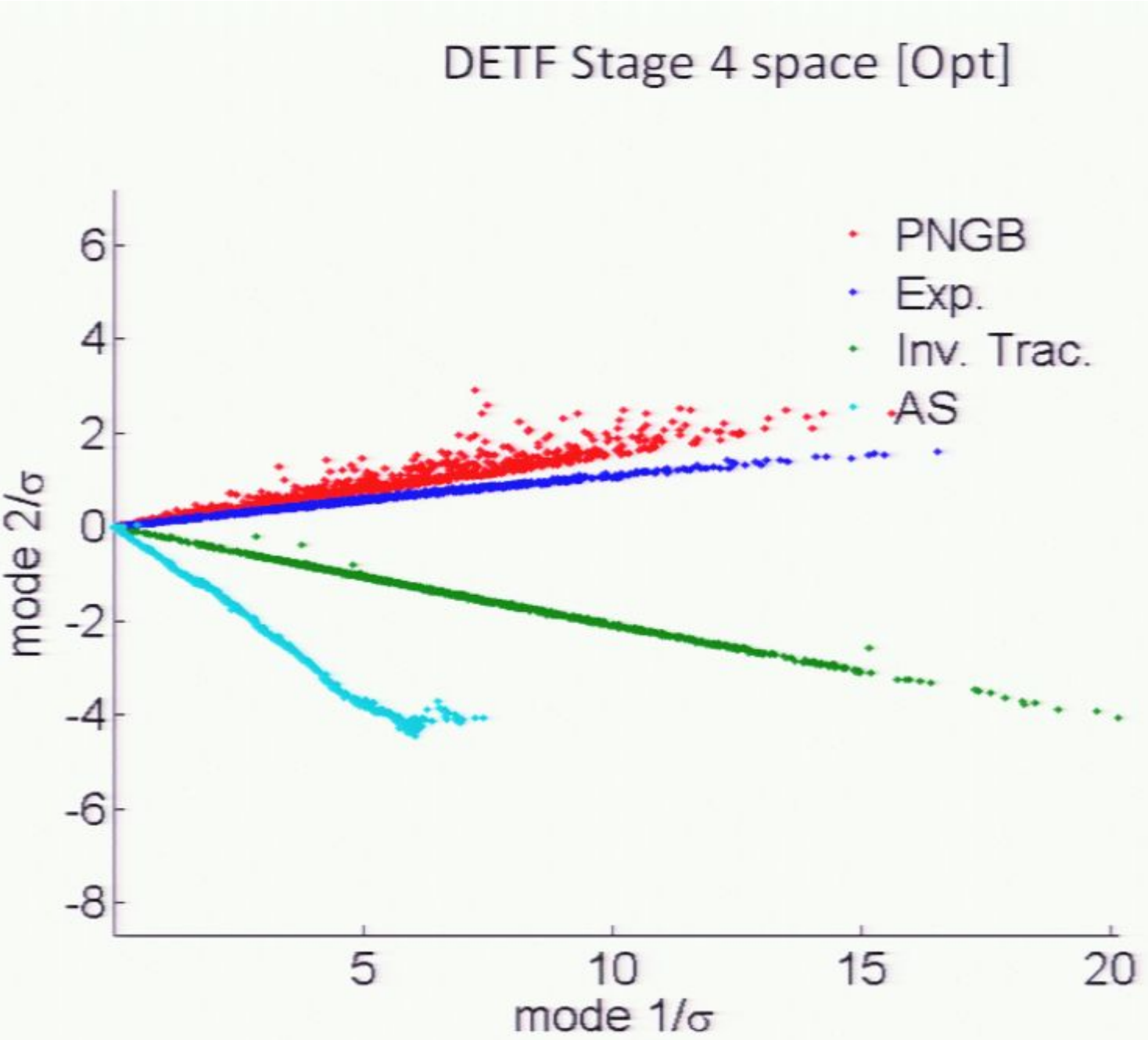
Stage 4 g

Stage 4 s

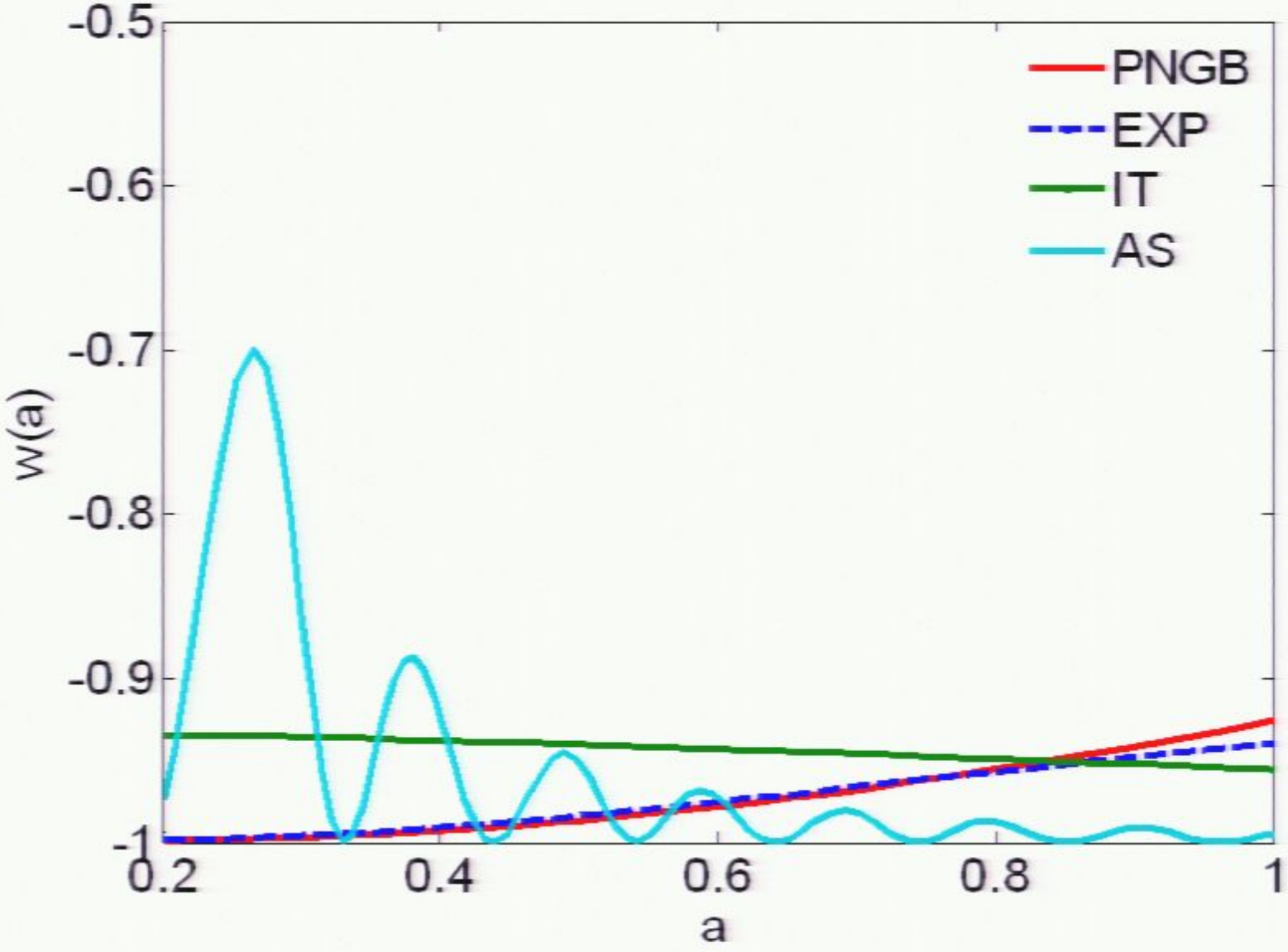
N.B. σ_i change too


DETF Stage 4 ground [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
4
2
0
-2
-4
-6
2
4
6
8
10
12

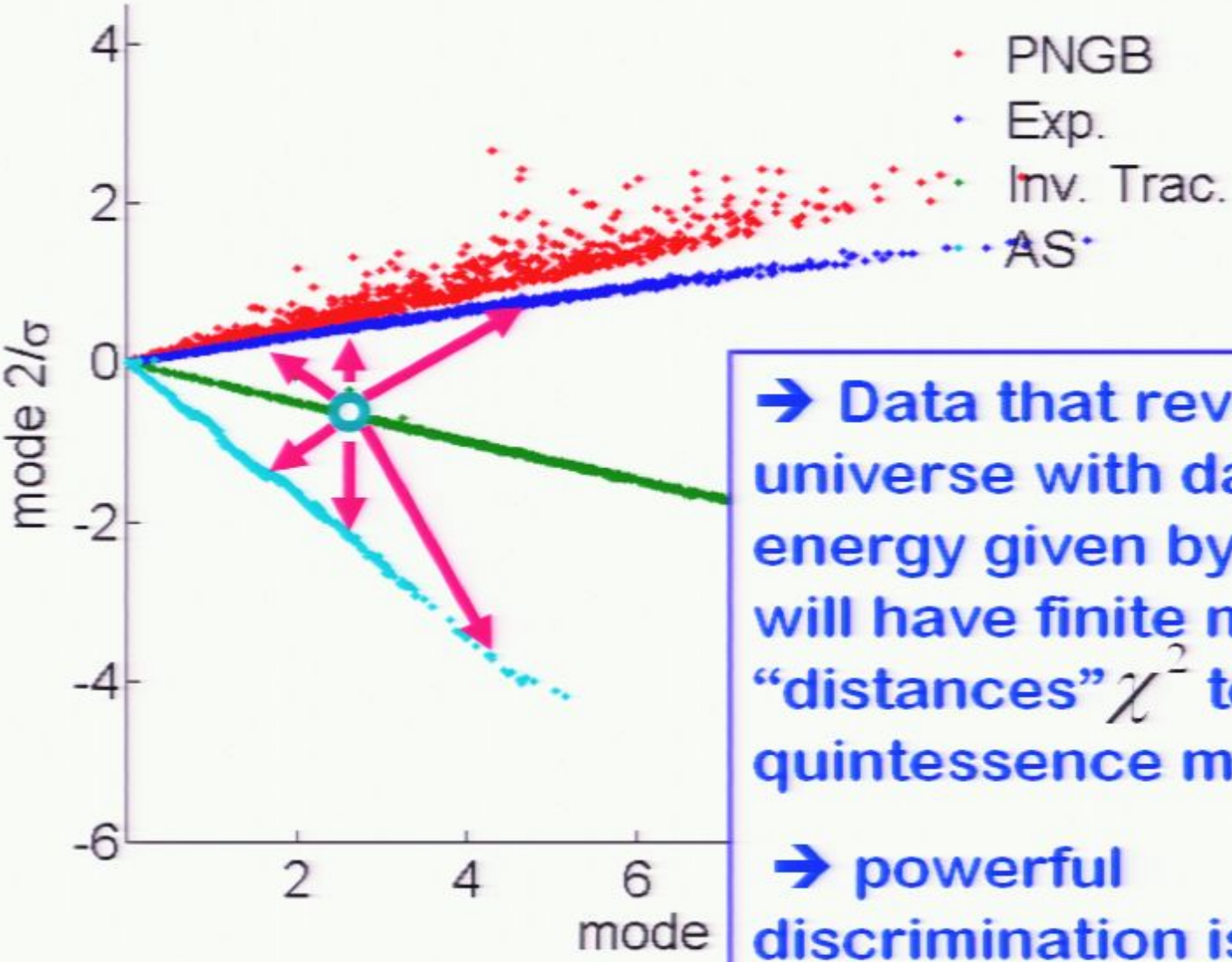

DETF Stage 4 ground [Opt]
PNGB
Exp.
Inv. Trac.
AS
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
mode 4/σ
0.5
1
1.5
mode 3/σ


DETF Stage 4 space [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
6
4
2
0
-2
-4
-6
-8
5
10
15
20

The different kinds of curves correspond to different "trajectories" in mode space (similar to FT's)



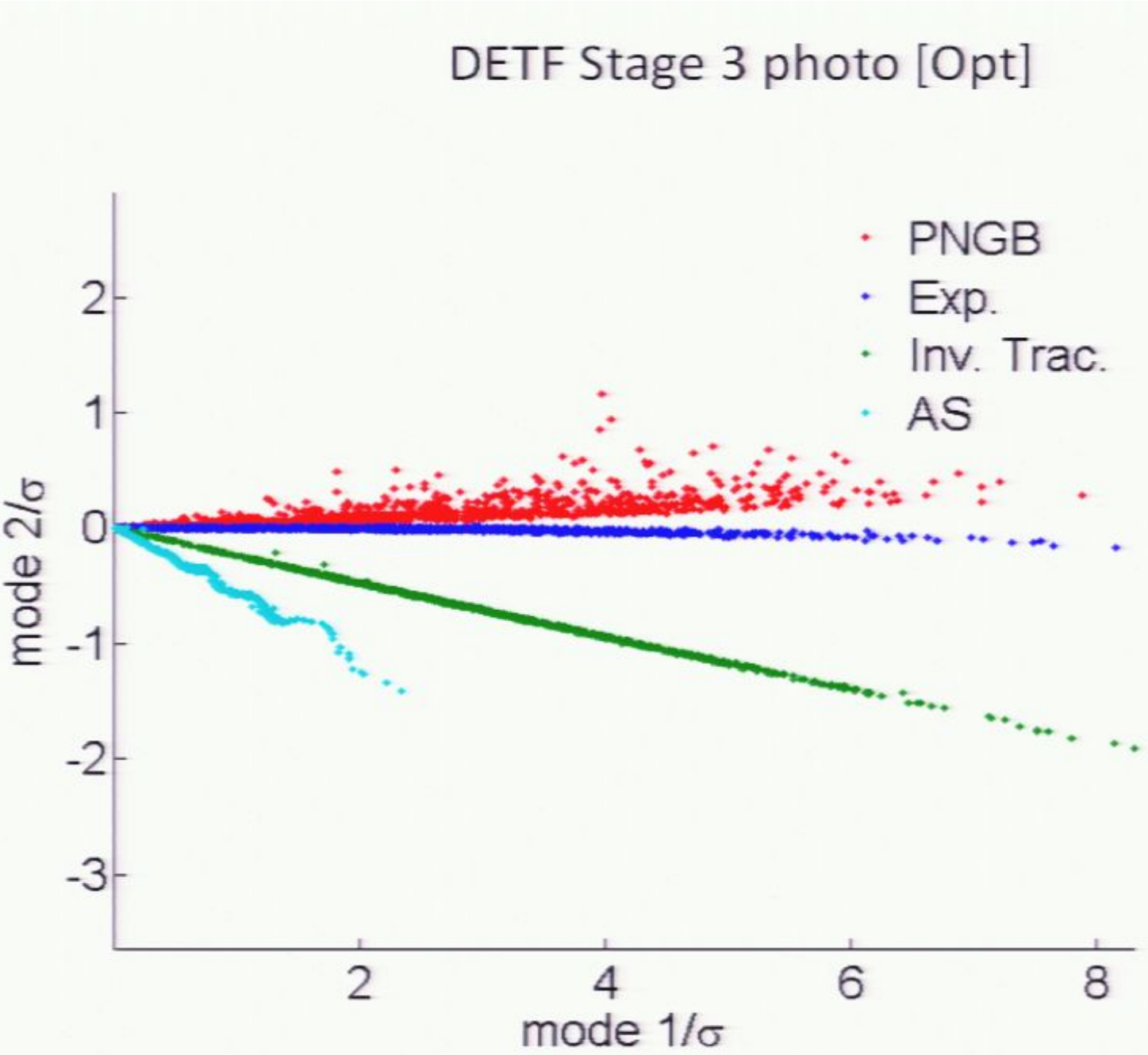
DETF Stage 4 ground

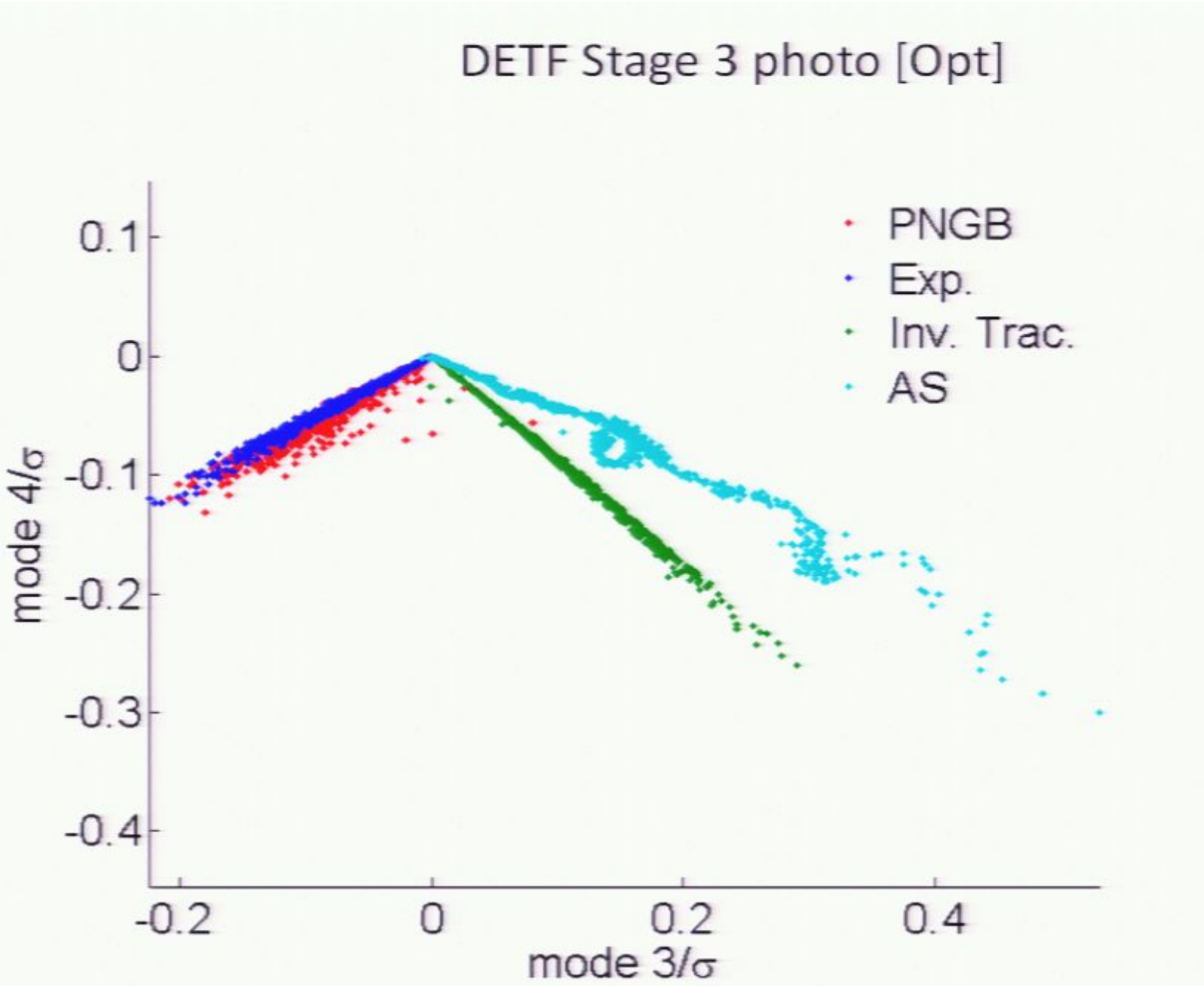


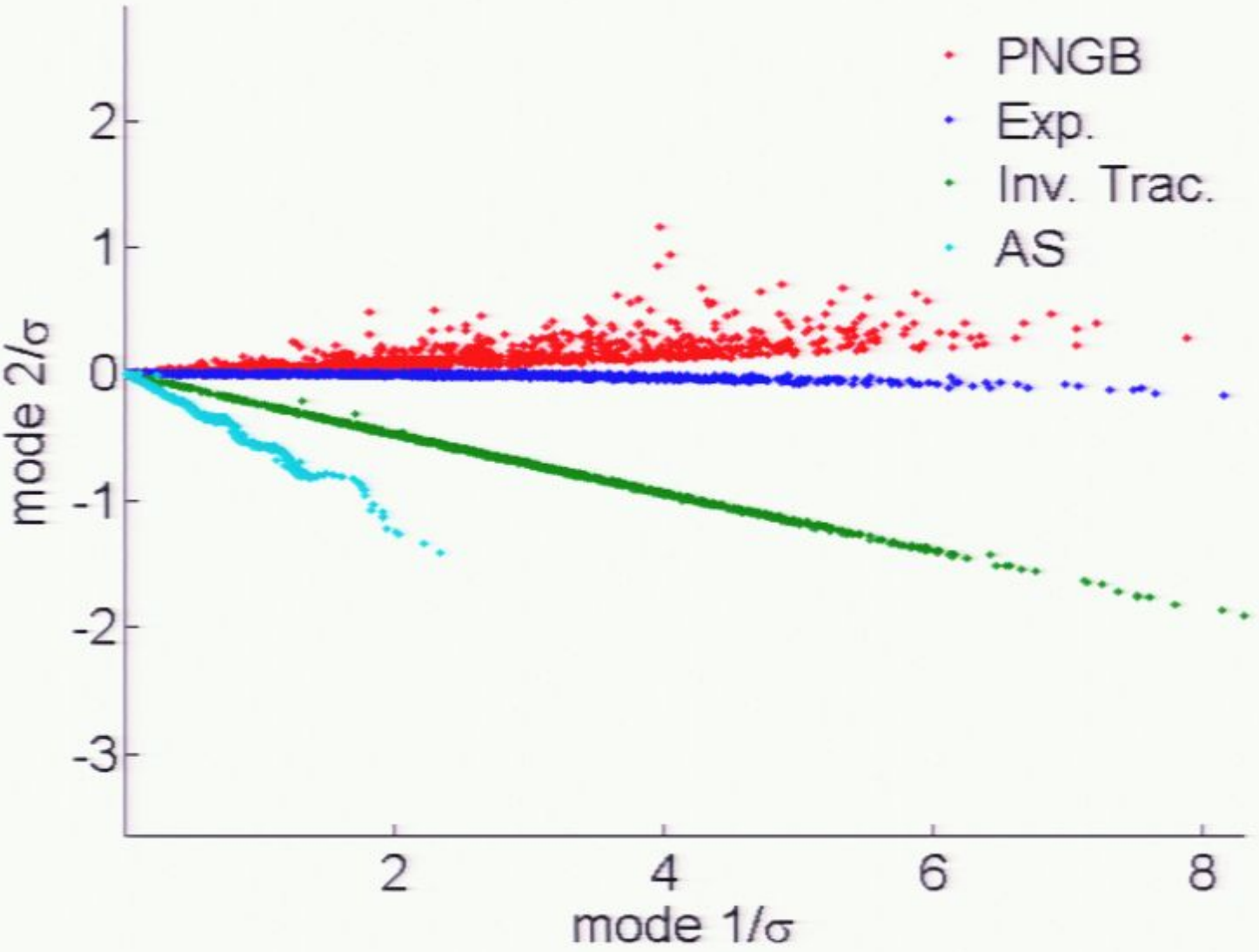
➔ Data that reveals a universe with dark energy given by " o " will have finite minimum "distances" χ^2 to other quintessence models

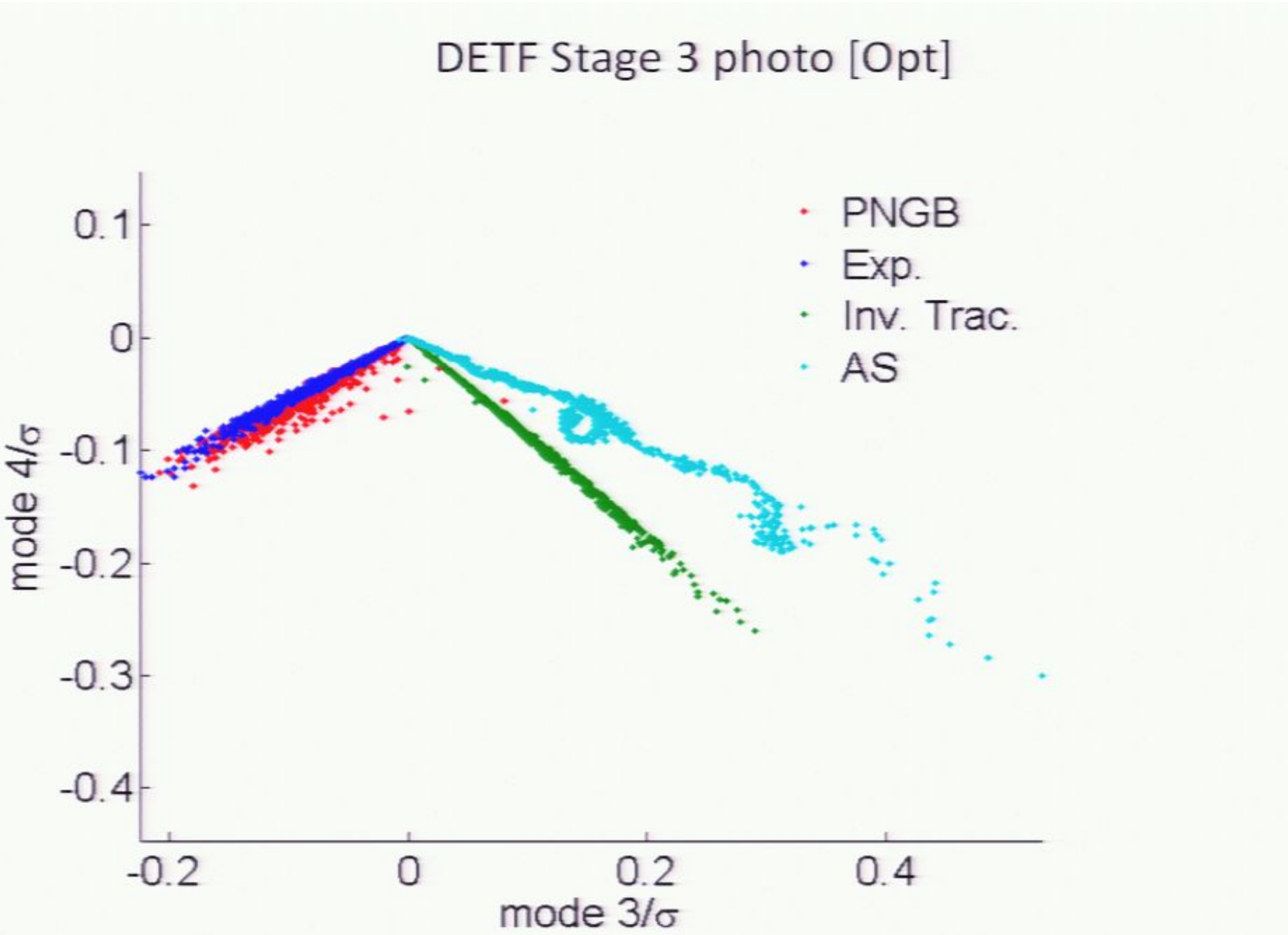
➔ powerful discrimination is possible.

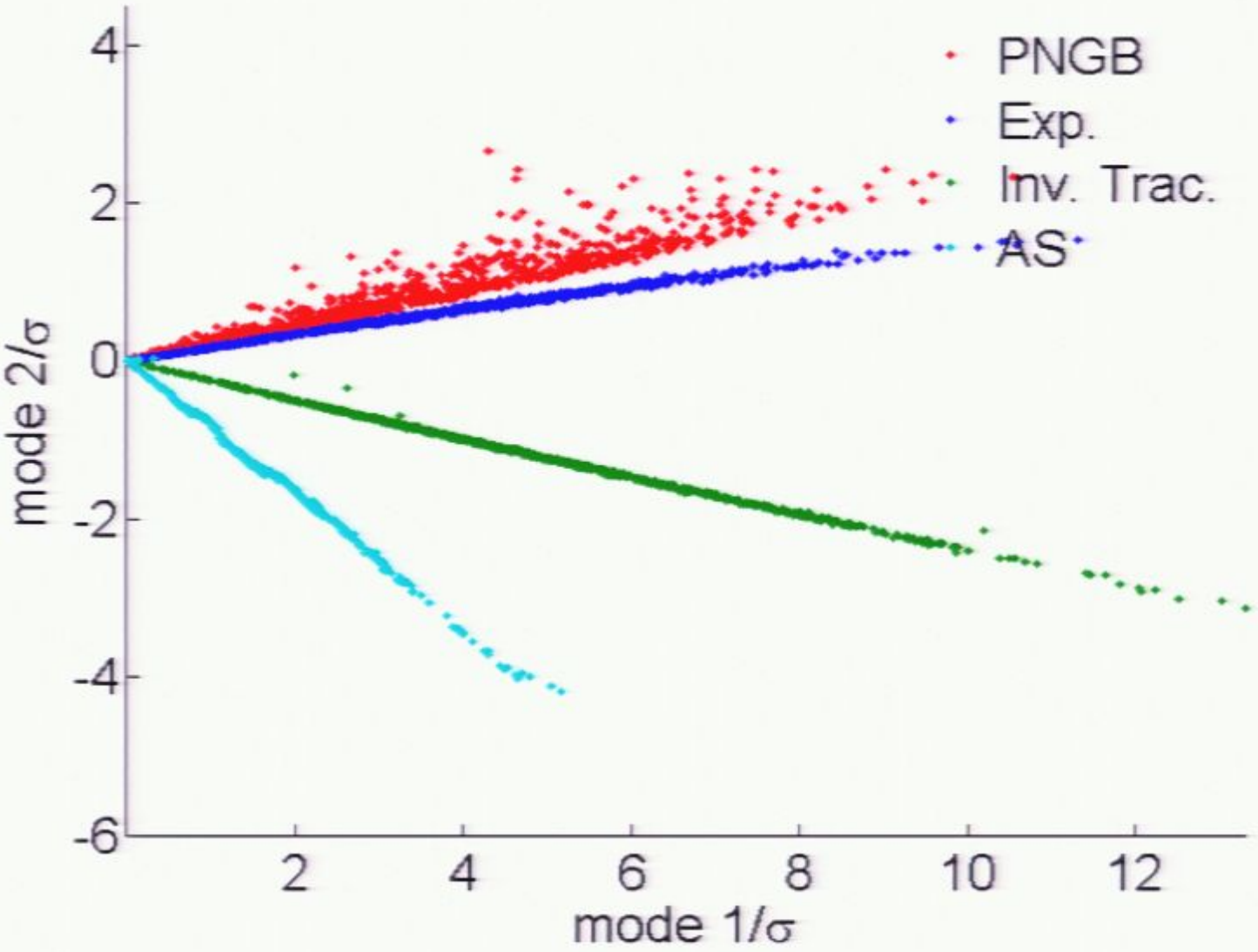
Consider discriminating power of each experiment (➔look at units on axes)

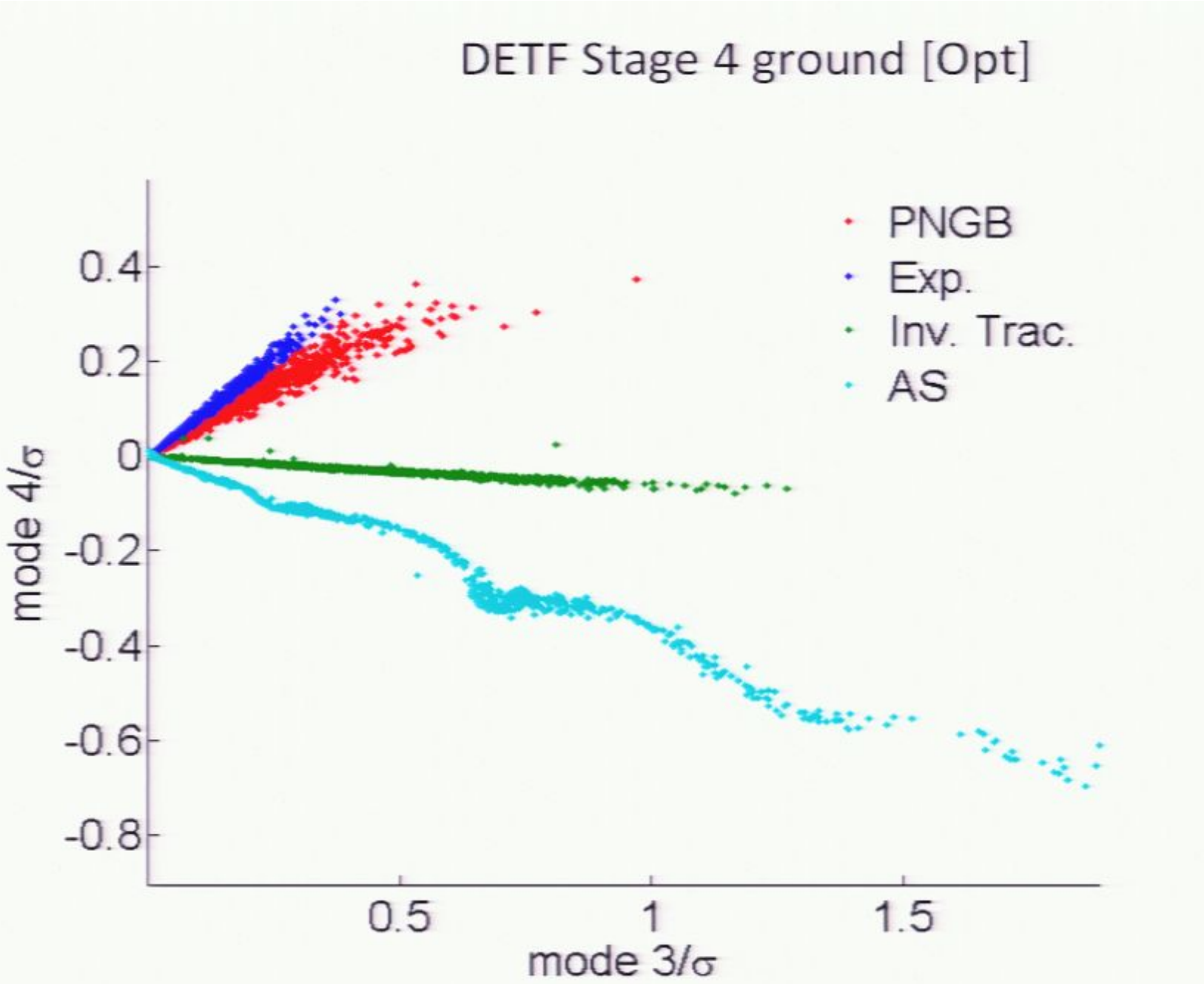

DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
2
1
0
-1
-2
-3
2
4
6
8

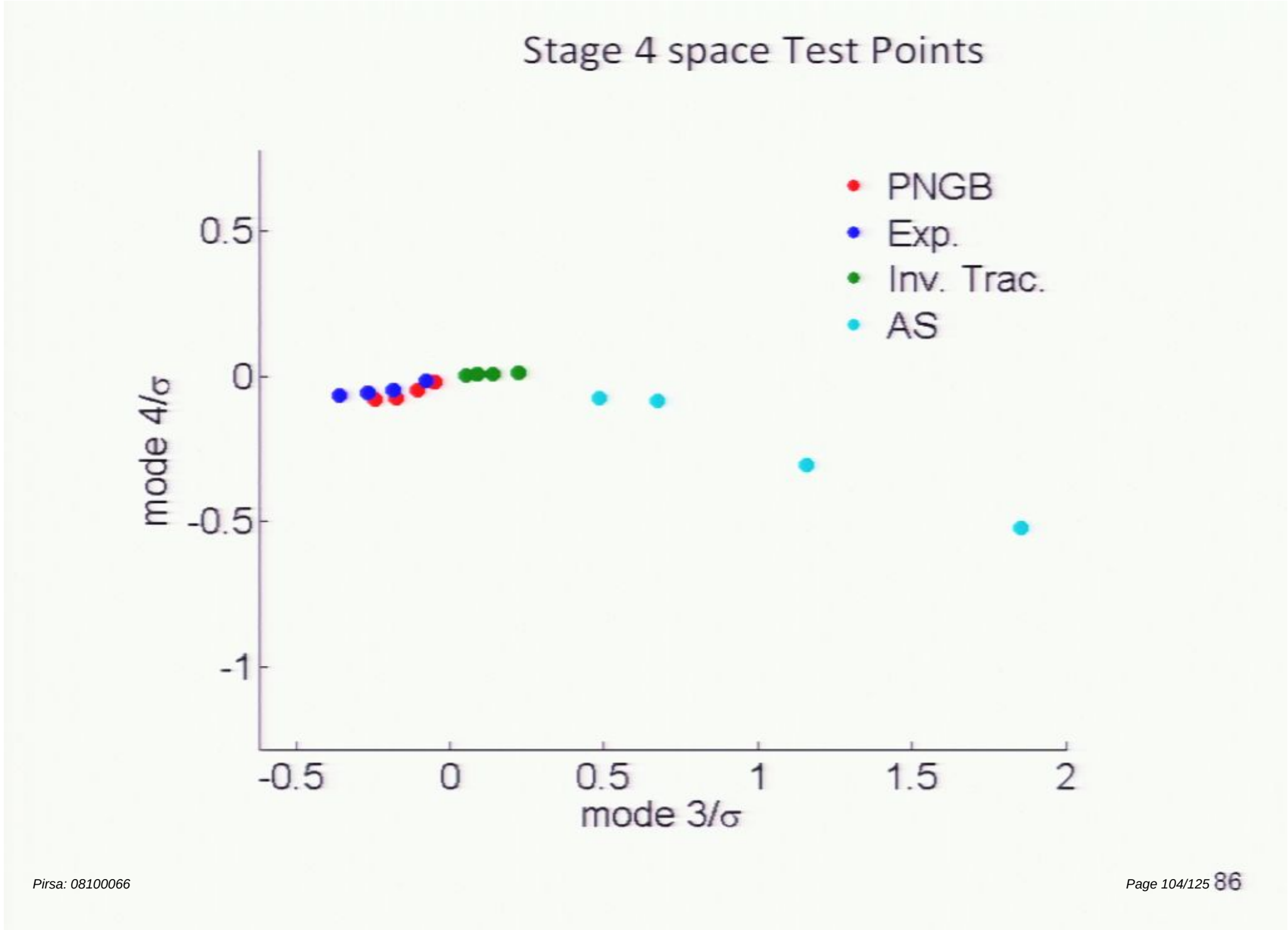

DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
0.1
0
-0.1
-0.2
-0.3
-0.4
mode 4/σ
-0.2
0
0.2
0.4
mode 3/σ

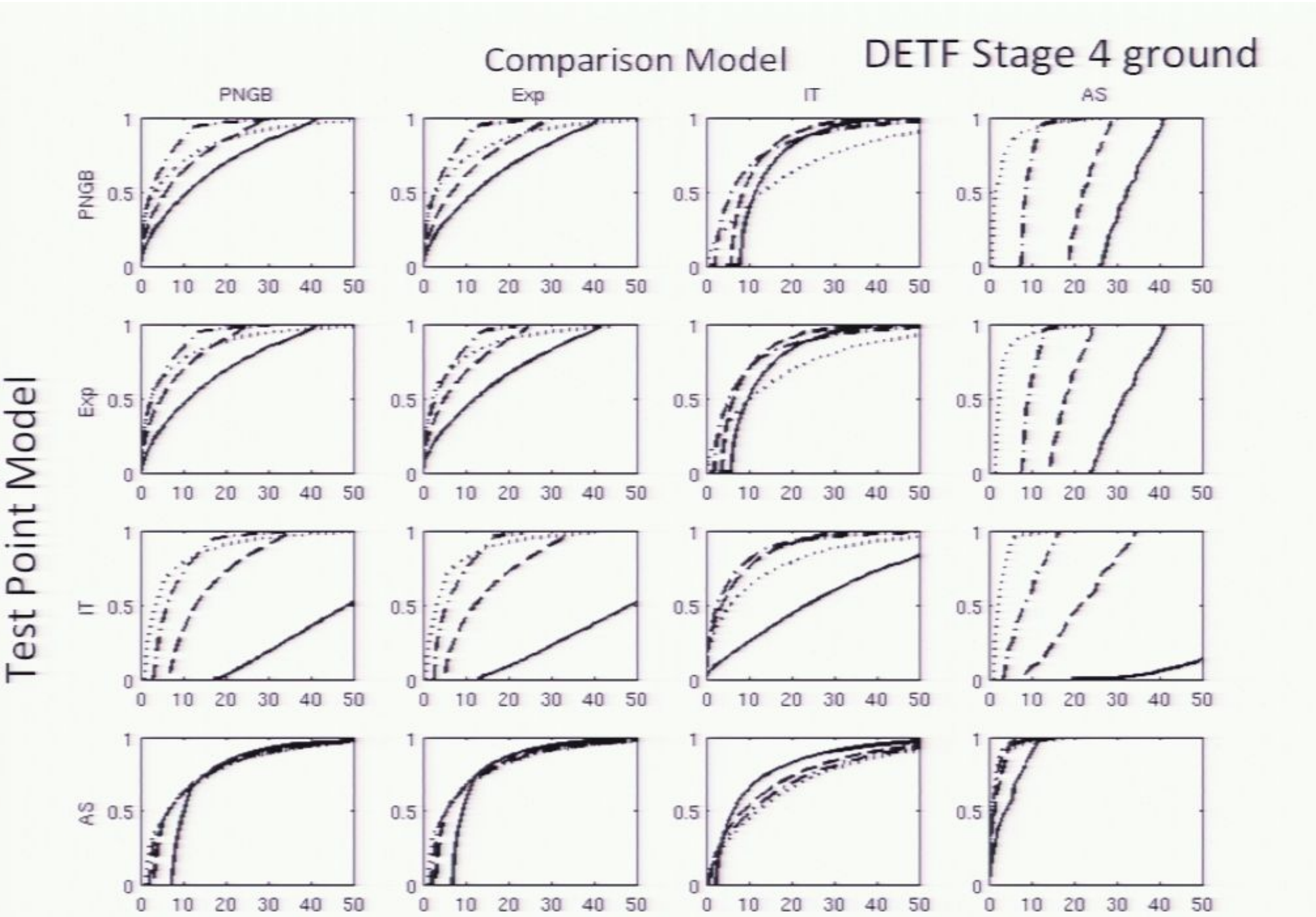

DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
2
1
0
-1
-2
-3
2
4
6
8


DETF Stage 3 photo [Opt]
PNGB
Exp.
Inv. Trac.
AS
0.1
0
-0.1
-0.2
-0.3
-0.4
mode 4/σ
-0.2
0
0.2
0.4
mode 3/σ


DETF Stage 4 ground [Opt]
PNGB
Exp.
Inv. Trac.
AS
mode 2/σ
mode 1/σ
4
2
0
-2
-4
-6
2
4
6
8
10
12


DETF Stage 4 ground [Opt]
PNGB
Exp.
Inv. Trac.
AS
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
mode 4/σ
0.5
1
1.5
mode 3/σ


Stage 4 space Test Points
PNGB
Exp.
Inv. Trac.
AS
0.5
0
-0.5
-1
mode 4/σ
-0.5
0
0.5
1
1.5
2
mode 3/σ


Comparison Model
DETF Stage 4 ground
Test Point Model
PNGB
Exp
IT
AS
0
0.5
1
0 10 20 30 40 50

DETF Stage 3 photo

A tabulation of χ^2 for each graph where the curve crosses the x-axis **(= gap)**
For the three parameters used here,
95% confidence → $\chi^2 = 7.82$,
99% → $\chi^2 = 11.36$.

Light orange > 95% rejection

Dark orange > 99% rejection

Blue: Ignore these because PNGB & Exp hopelessly similar, plus self-comparisons

PNGB	PNGB	Exp	IT	AS
Point 1	0.001	0.001	0.1	0.2
Point 2	0.002	0.01	0.5	1.8
Point 3	0.004	0.04	1.2	6.2
Point 4	0.01	0.04	1.6	10.0
Exp				
Point 1	0.004	0.001	0.1	0.4
Point 2	0.01	0.001	0.4	1.8
Point 3	0.03	0.001	0.7	4.3
Point 4	0.1	0.01	1.1	9.1
IT				
Point 1	0.2	0.1	0.001	0.2
Point 2	0.5	0.4	0.0004	0.7
Point 3	1.0	0.7	0.001	3.3
Point 4	2.7	1.8	0.01	16.4
AS				
Point 1	0.1	0.1	0.1	0.0001
Point 2	0.2	0.1	0.1	0.0001
Point 3	0.2	0.2	0.1	0.0002
Point 4	7.4	7.0	2.6	0.001

Comments on model discrimination

- Principle component w(a) "modes" offer a space in which straightforward tests of discriminating power can be made.

- The DETF Stage 4 data is approaching the threshold of resolving the structure that our scalar field models form in the mode space.

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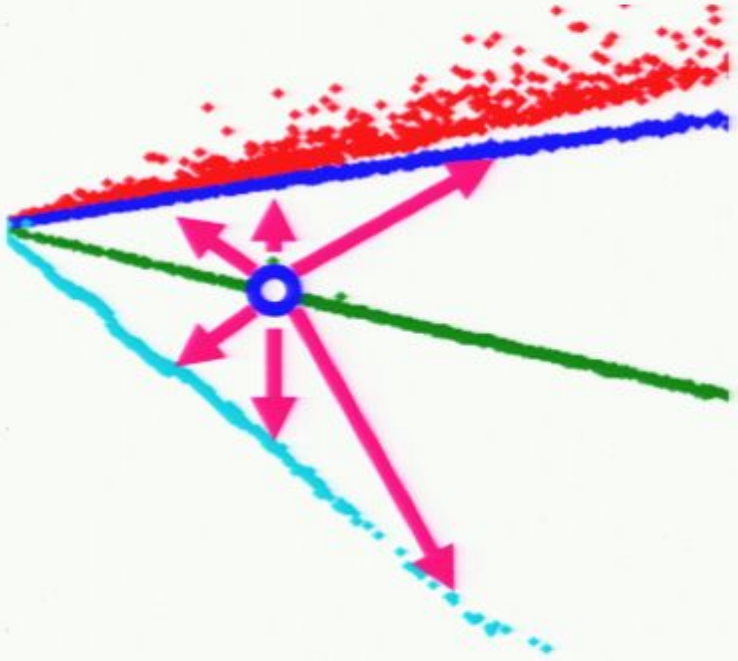

Followup questions:

→ In what ways might the choice of DE parameters have skewed the DETF results?

→ What impact can these data sets have on specific DE models (vs abstract parameters)?

→ To what extent can these data sets deliver discriminating power between specific DE models?

→ How is the DoE/ESA/NASA Science Working Group looking at these questions?

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- DETF Stage 3: Poor
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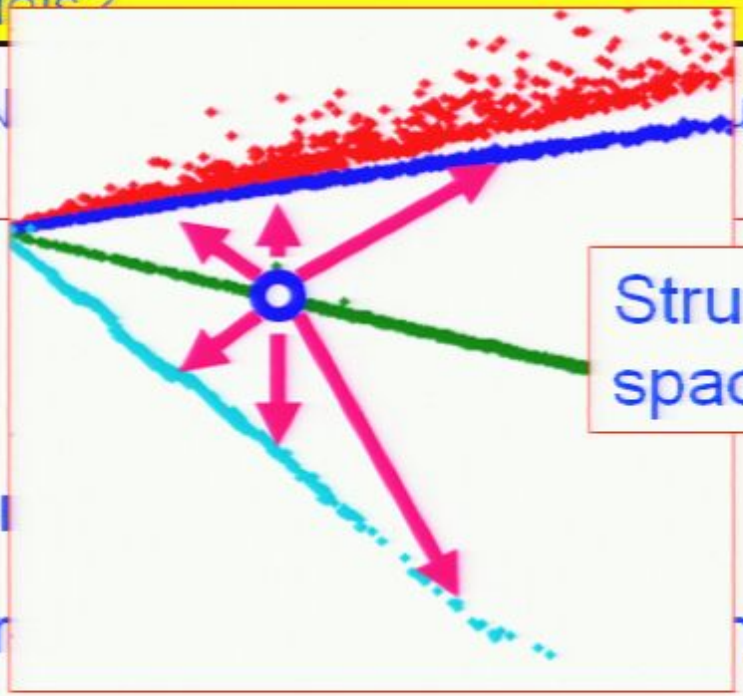

Structure in mode space

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DoE/ESA/NASA JDEM Science Working Group

➔ Update agencies on figures of merit issues

➔ formed Summer 08

➔ finished ~now (moving on to SCG)

➔ Use w-eigenmodes to get more complete picture

➔ also quantify deviations from Einstein gravity

➔ For today: Something we learned about normalizing modes

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

$$\Delta\vec{w} = \sum_i c_i \vec{f}_i$$

The c_i are independently measured qualities with errors σ_i

Define

$$\vec{f}_i^{\,D} \equiv \vec{f}_i / \sqrt{\Delta a}$$

which obey continuum normalization:

$$\sum f_i^D(k) f_j^D(k) \Delta a = \delta_{ij}$$

then

$$\Delta\vec{w} = \sum_i c_i^D \vec{f}_i^{\,D}$$

where

$$c_i^D \equiv c_i \times \sqrt{\Delta a}$$

Q: Why?

A: For lower modes, f_j^D has typical *grid independent* "height" O(1), so one can more directly relate values of $\sigma_i^D \equiv \sigma_i \times \sqrt{\Delta a}$ to one's thinking (priors) on $\Delta\vec{w}$

$$\Delta\vec{w} = \sum_i c_i \vec{f}_i = \sum_i c_i^D \vec{f}_i^D$$

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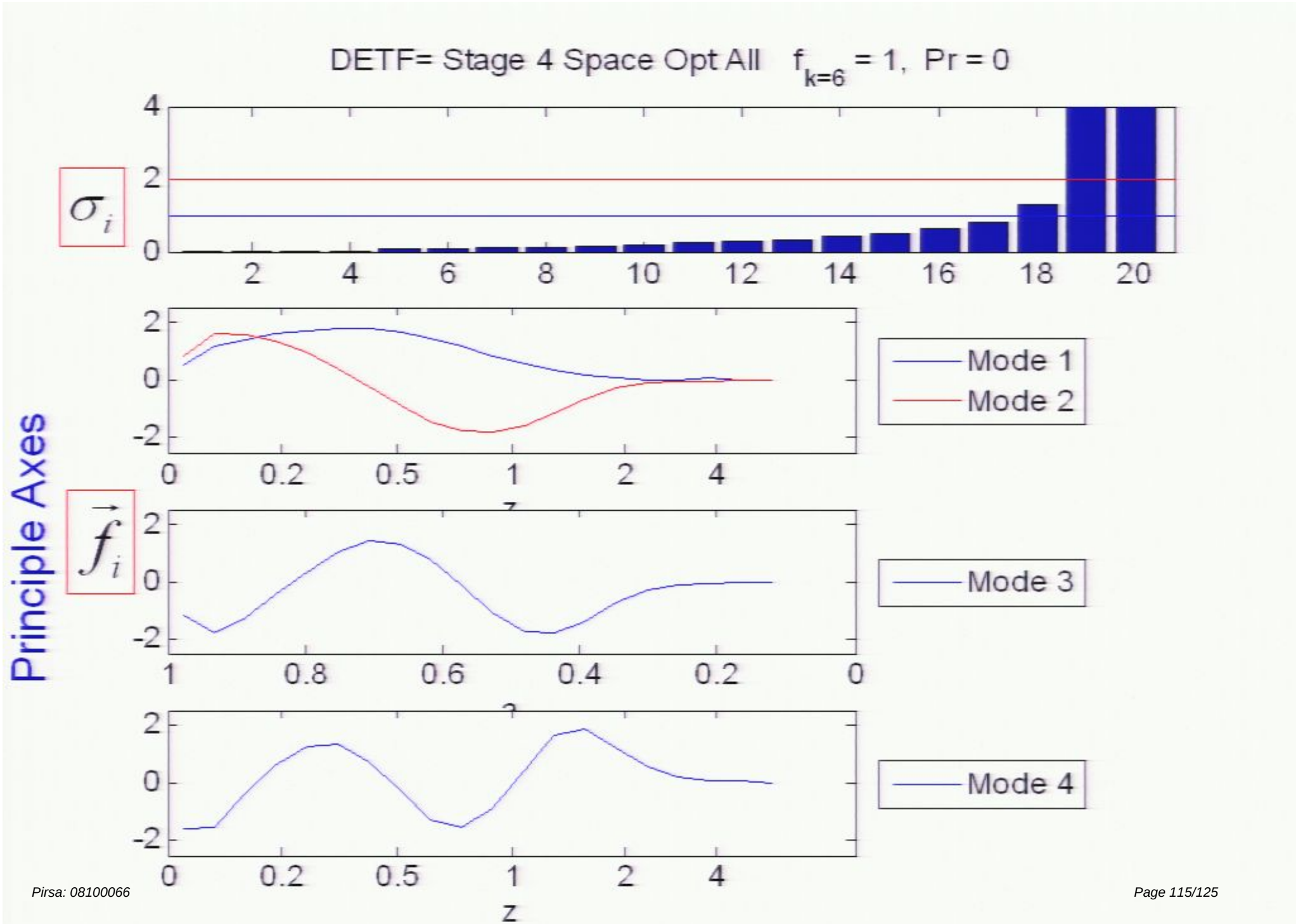
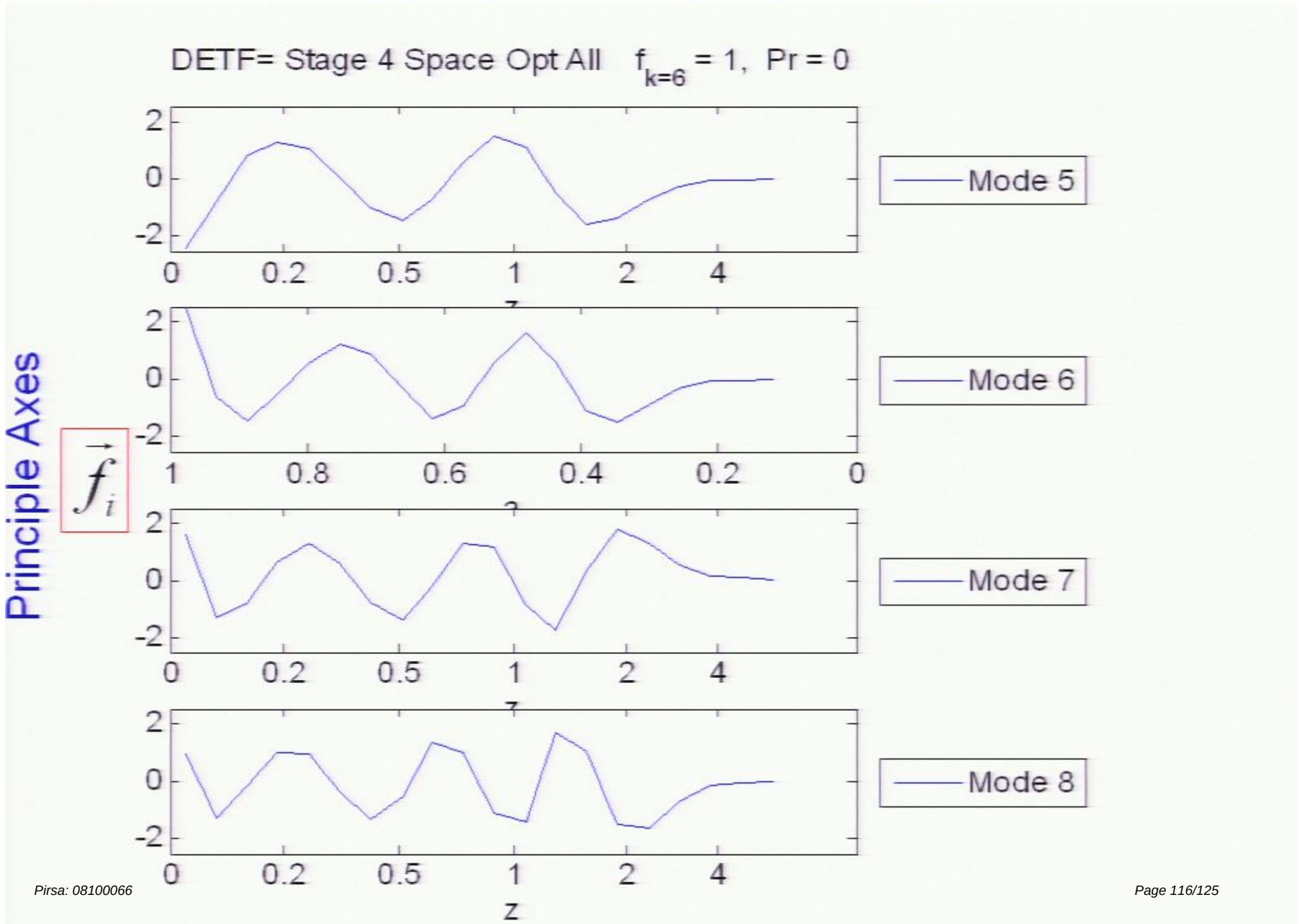

DETF= Stage 4 Space Opt All $f_{k=6} = 1$, Pr = 0
σ_i
$\vec{f}_i$
Principle Axes
Mode 1
Mode 2
Mode 3
Mode 4
z


DETF= Stage 4 Space Opt All $f_{k=6}$ = 1, Pr = 0
Principle Axes
$\vec{f}_i$
Mode 5
Mode 6
Mode 7
Mode 8
z

Upshot: More modes are interesting ("well measured" in a grid invariant sense) than previously thought.

Summary

→ In what ways might the choice of DE parameters have skewed the DETF results?

A: Only by an overall (possibly important) rescaling

→ What impact can these data sets have on specific DE models (vs abstract parameters)?

A: Very similar to DETF results in w0-wa space

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Interesting contribution to discussion of Stage 4 (if you believe scalar field modes)

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→ How is the DoE/ESA/NASA Science Working Group looking at these questions?

i) Using w(a) eigenmodes

ii) Revealing value of higher modes

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