Europlanet Science Congress 2026

The Hague, The Netherlands

Granular Column Collapse on Extra-Terrestrial Bodies

Supplementary Material

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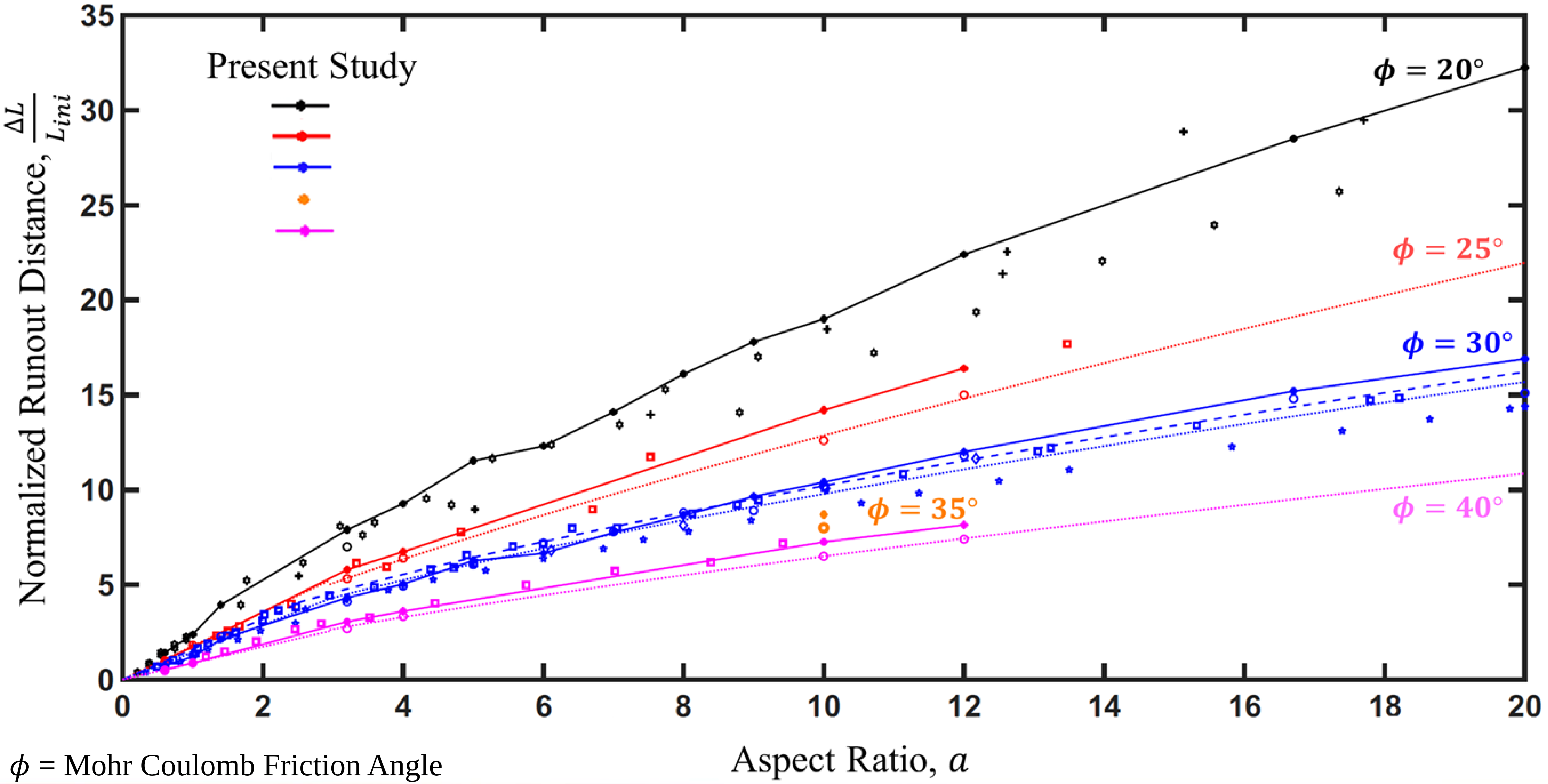
Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Part A: Numerical Model Validation

For Earth ($g = 9.81\ m/s^2$)

Normalized Runout Distance vs. Aspect Ratio
For Earth ($g = 9.81\ m/s^2$)

Detailed Legend and Case Definitions: see Next Slide



ϕ = Mohr Coulomb Friction Angle

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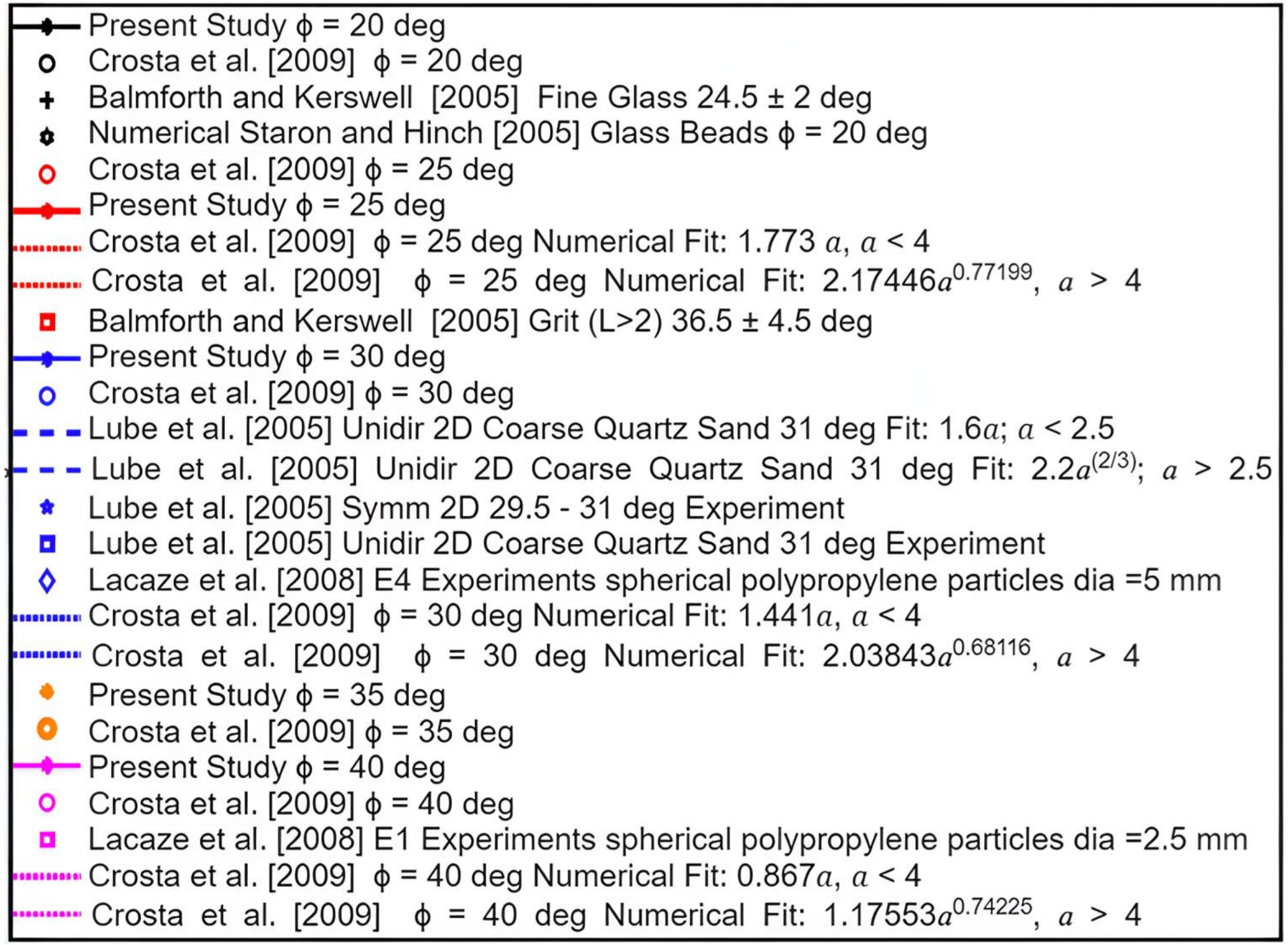
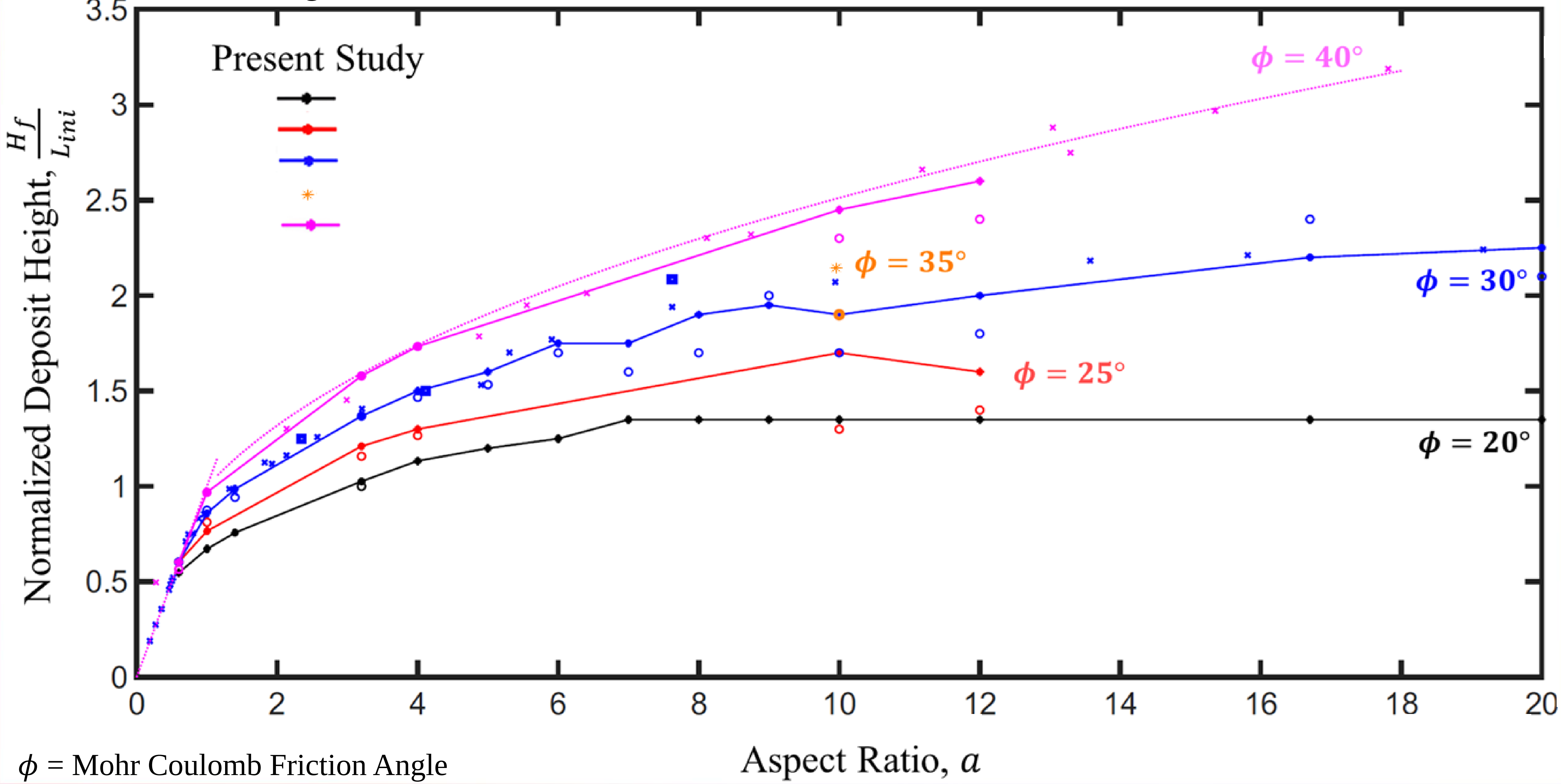
Detailed Legend and Case Definitions



ϕ = Mohr Coulomb Friction Angle

Normalized Deposit Height vs. Aspect Ratio
For Earth ($g = 9.81\ m/s^2$)

Detailed Legend and Case Definitions: see Next Slide



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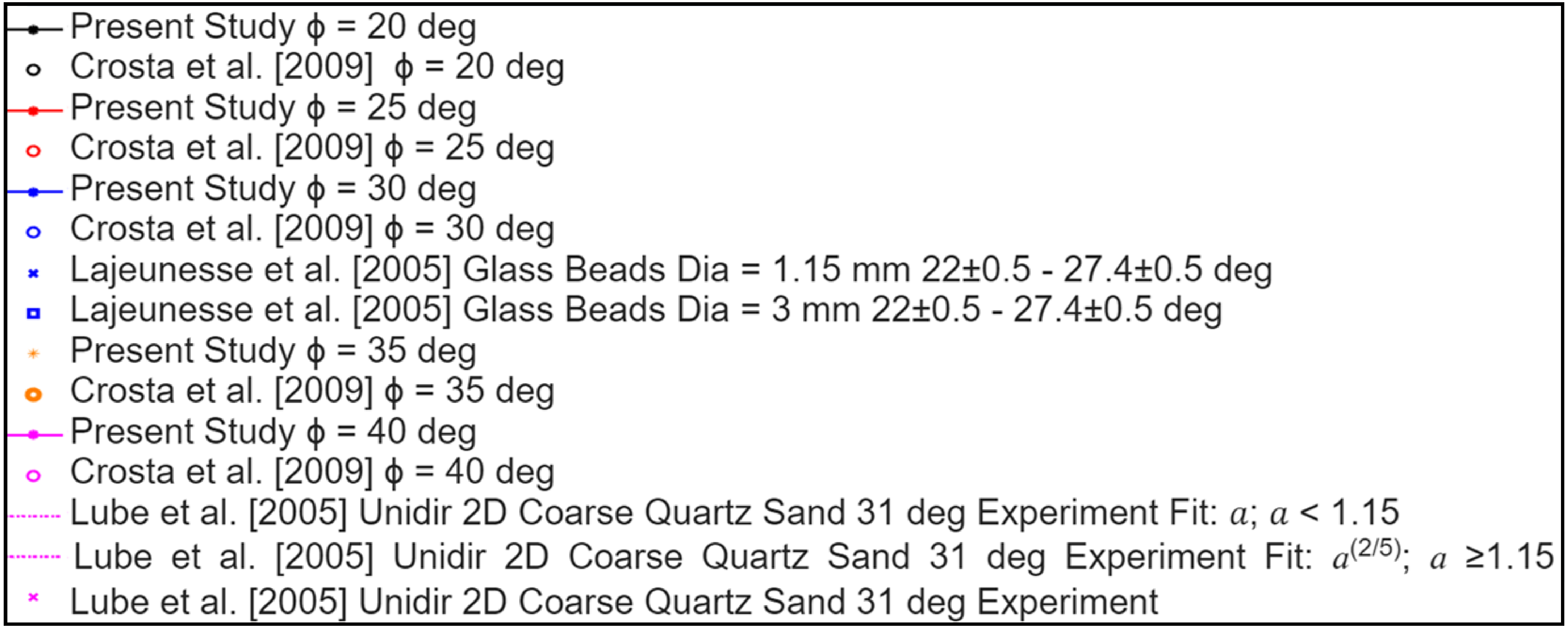

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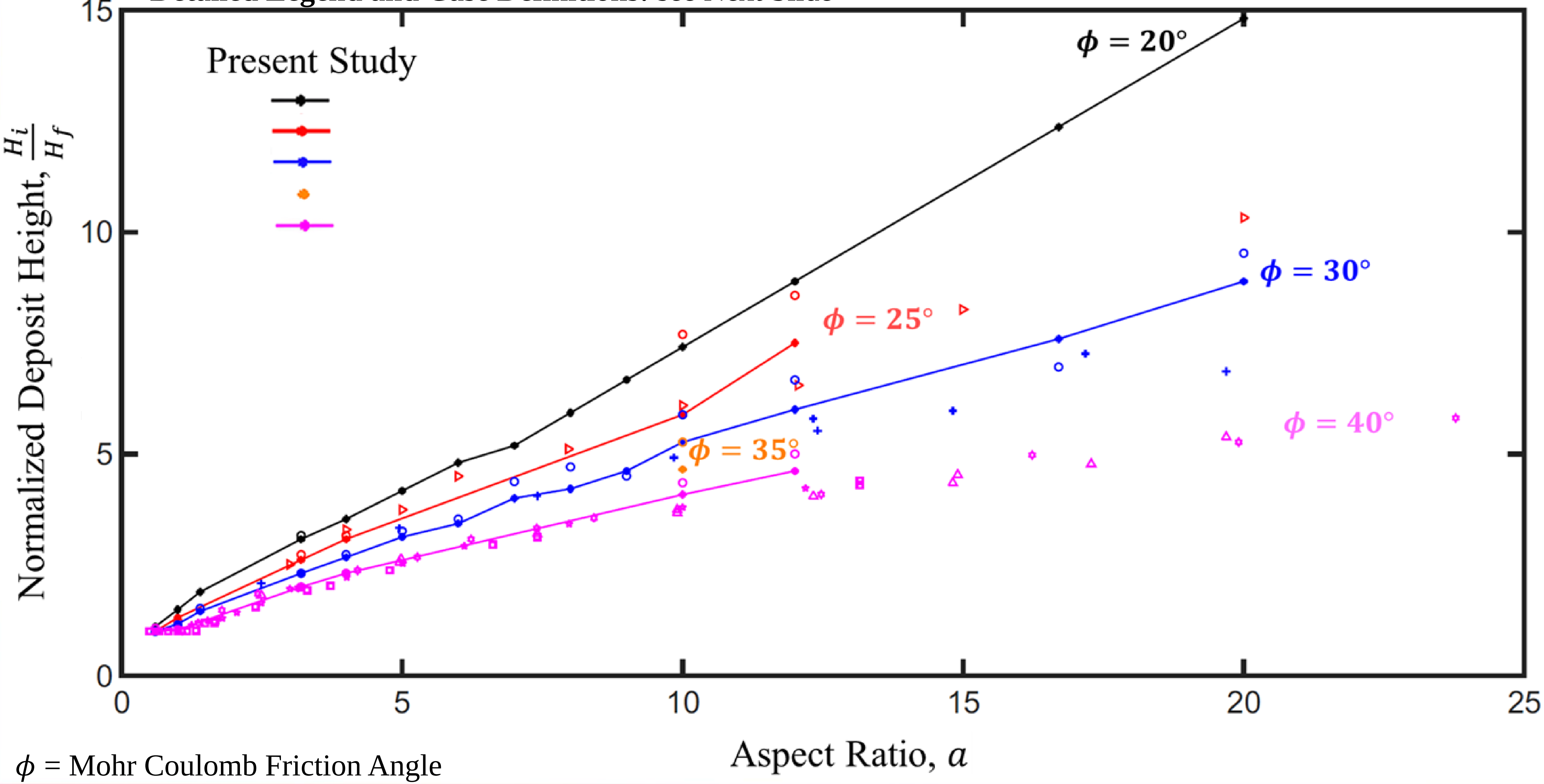

ϕ = Mohr Coulomb Friction Angle

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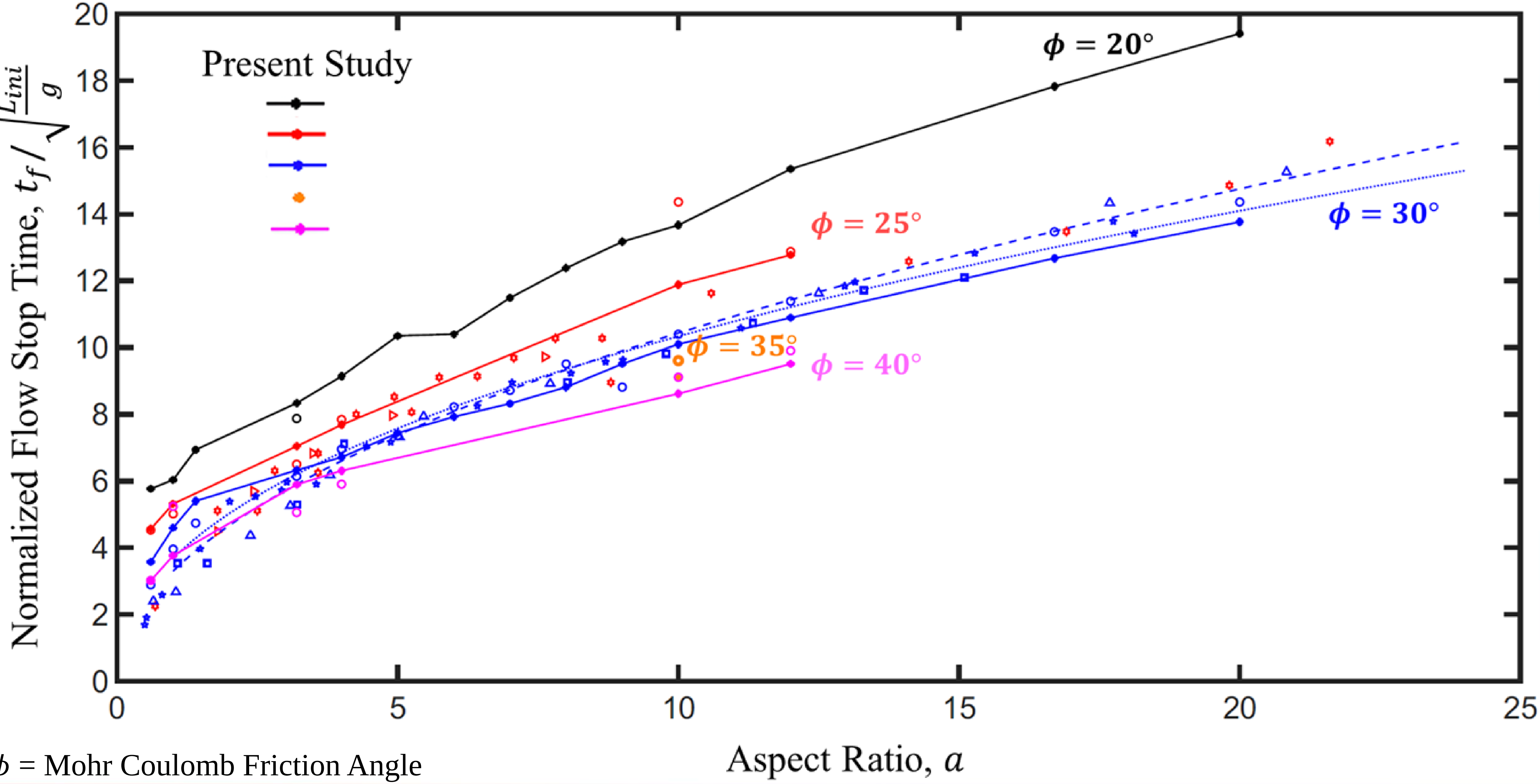
Detailed Legend and Case Definitions

Present Study ϕ = 20 deg
Crosta et al. [2009] ϕ = 20 deg
Present Study ϕ = 25 deg
Crosta et al. [2009] ϕ = 25 deg
Lacaze et al. [2008] Numerical N3 Results spherical polypropylene particles Dia = 2.5 mm
Present Study ϕ = 30 deg
Crosta et al. [2009] ϕ = 30 deg
Balmforth and Kerswell [2005] Fine Glass (L = 2) 24.5 ± 2 deg
Present Study ϕ = 35 deg
Crosta et al. [2009] ϕ = 35 deg
Present Study ϕ = 40 deg
Crosta et al. [2009] ϕ = 40 deg
Balmforth and Kerswell [2005] Grit (L > 2) 36.5 ± 4.5 deg
Balmforth and Kerswell [2005] Grit (L = 2) 36.5 ± 4.5 deg
Lacaze et al. [2008] E4 Experiments spherical polypropylene particles Dia = 5 mm
Lacaze et al. [2008] E1 and E2 Experiments spherical polypropylene particles Dia = 2.5 mm

ϕ = Mohr Coulomb Friction Angle

Normalized Flow Stop Time vs. Aspect Ratio
For Earth ($g = 9.81\ m/s^2$)

Detailed Legend and Case Definitions: see Next Slide



ϕ = Mohr Coulomb Friction Angle

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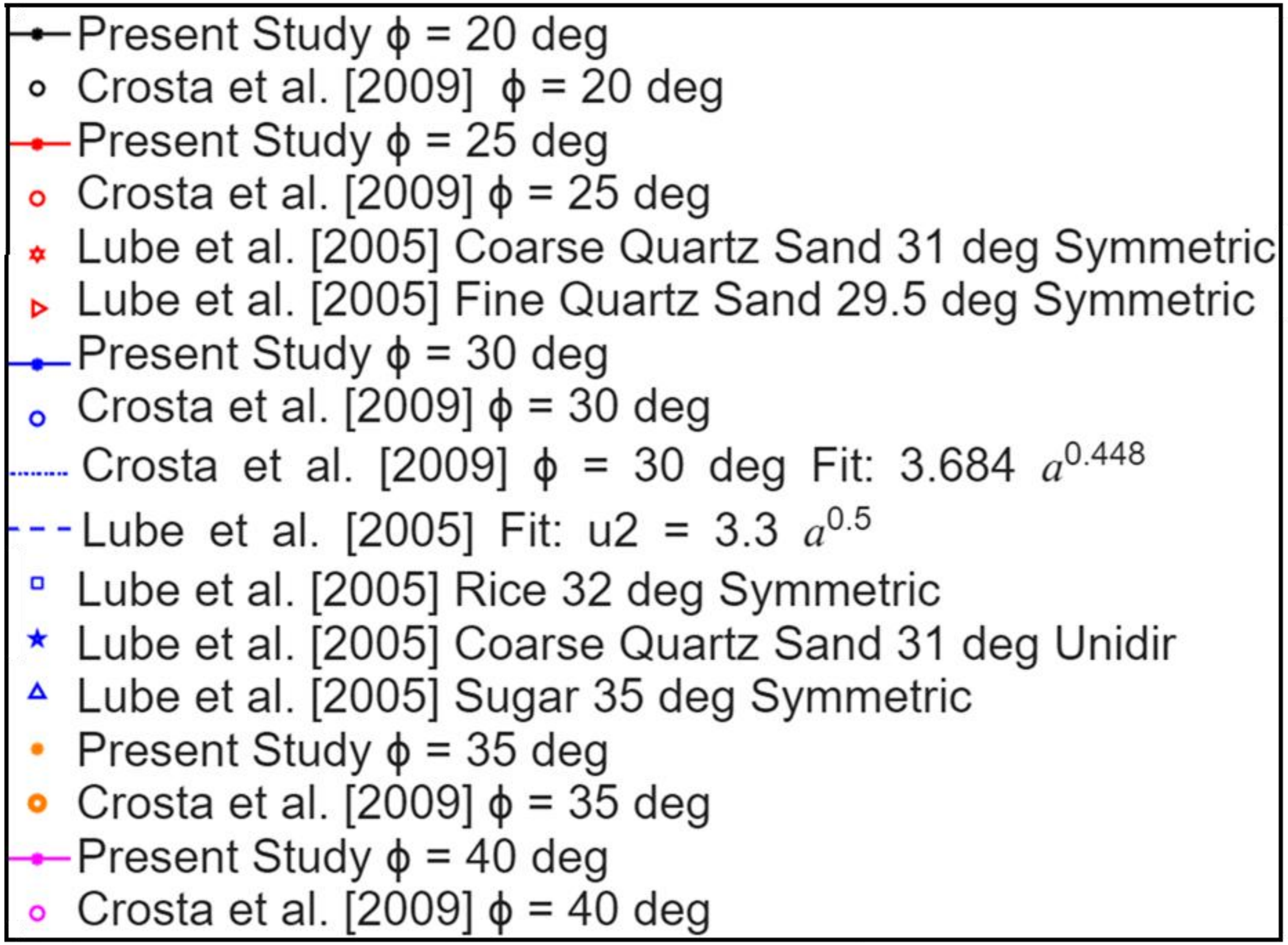
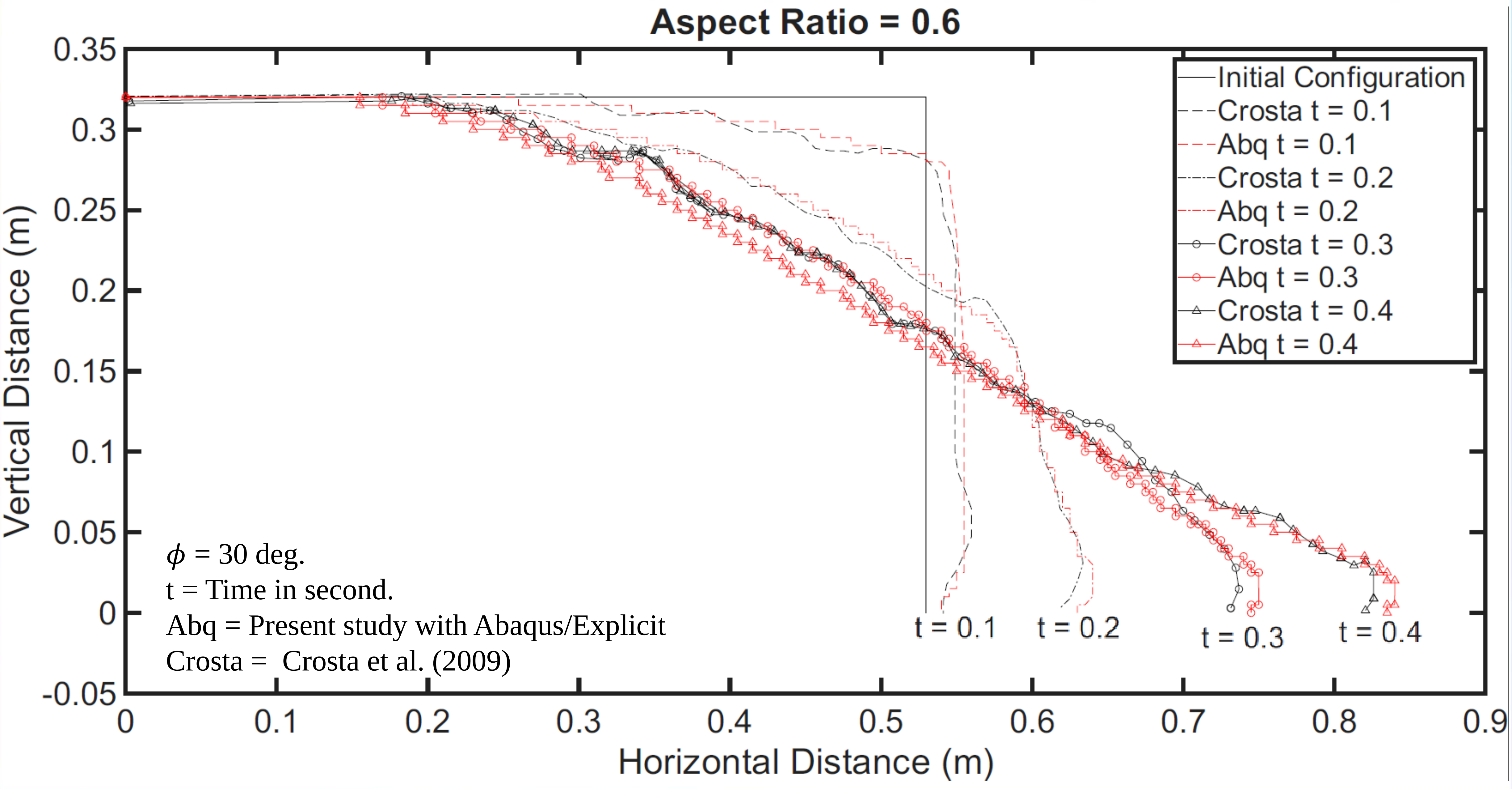
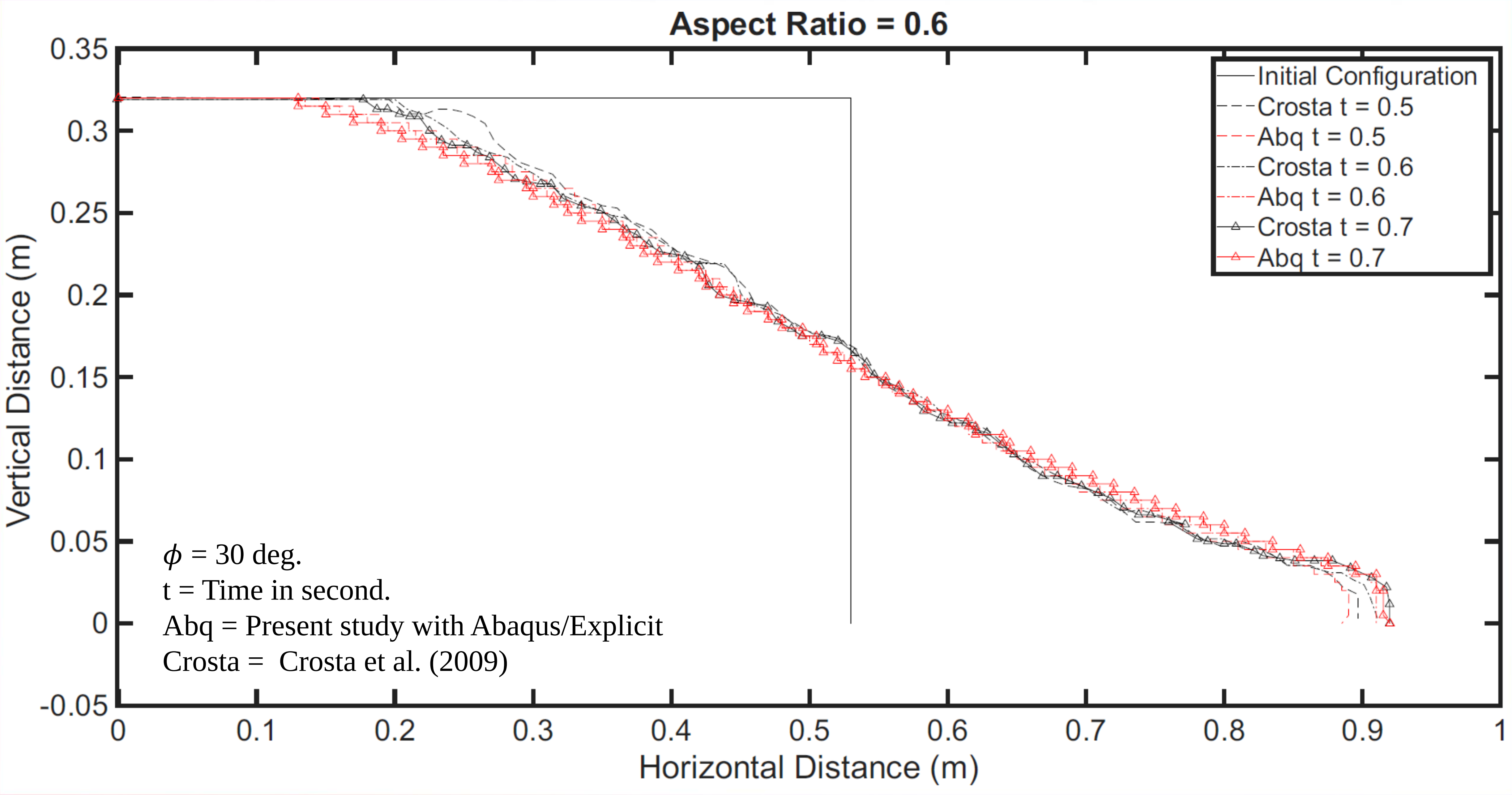
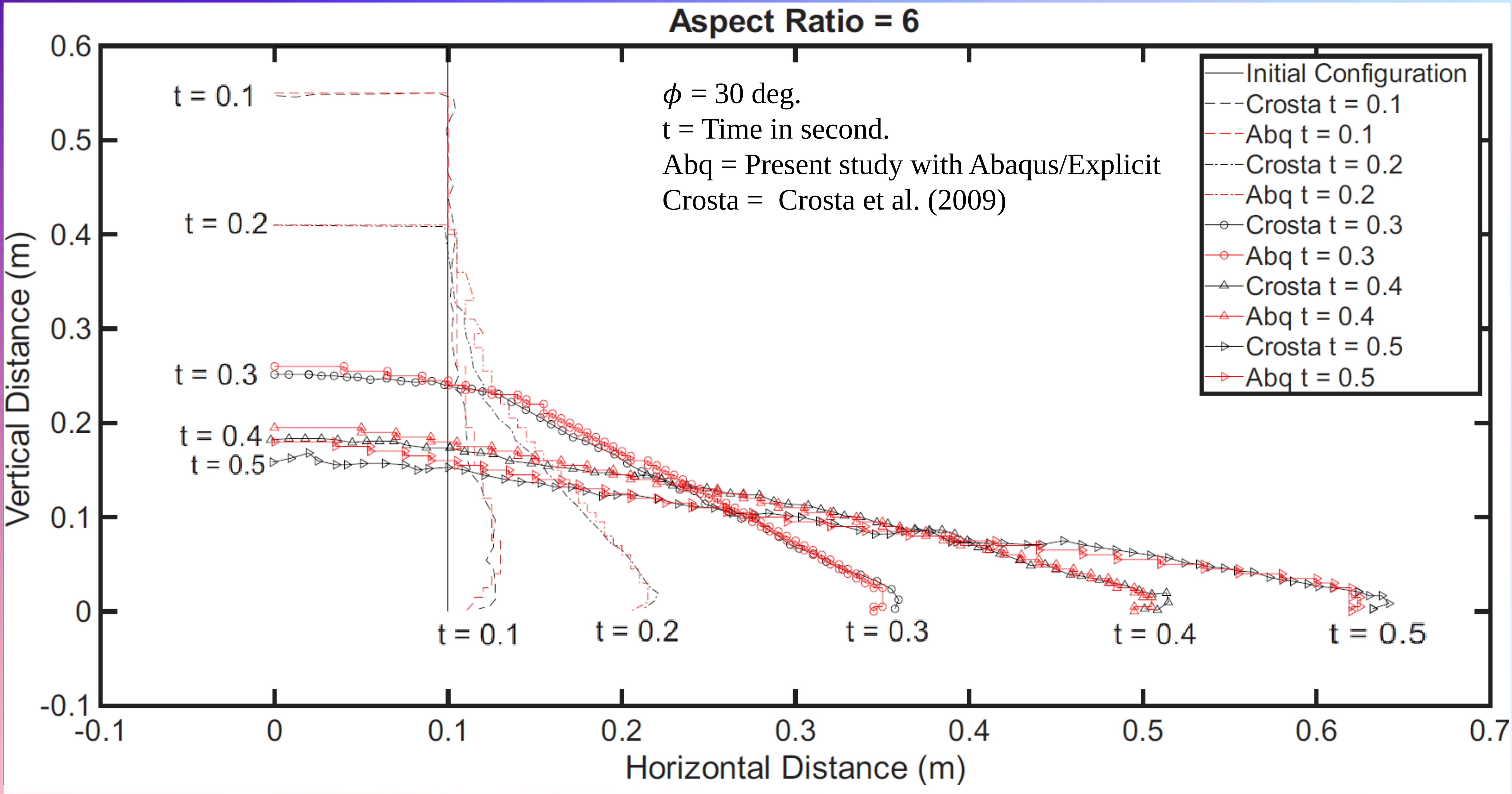
Detailed Legend and Case Definitions



ϕ = Mohr Coulomb Friction Angle


Aspect Ratio = 0.6
Initial Configuration
Crosta t = 0.1
Abq t = 0.1
Crosta t = 0.2
Abq t = 0.2
Crosta t = 0.3
Abq t = 0.3
Crosta t = 0.4
Abq t = 0.4
Vertical Distance (m)
Horizontal Distance (m)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ϕ = 30 deg.
t = Time in second.
Abq = Present study with Abaqus/Explicit
Crosta = Crosta et al. (2009)
t = 0.1
t = 0.2
t = 0.3
t = 0.4


Aspect Ratio = 0.6
Vertical Distance (m)
Horizontal Distance (m)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Initial Configuration
Crosta t = 0.5
Abq t = 0.5
Crosta t = 0.6
Abq t = 0.6
Crosta t = 0.7
Abq t = 0.7
ϕ = 30 deg.
t = Time in second.
Abq = Present study with Abaqus/Explicit
Crosta = Crosta et al. (2009)



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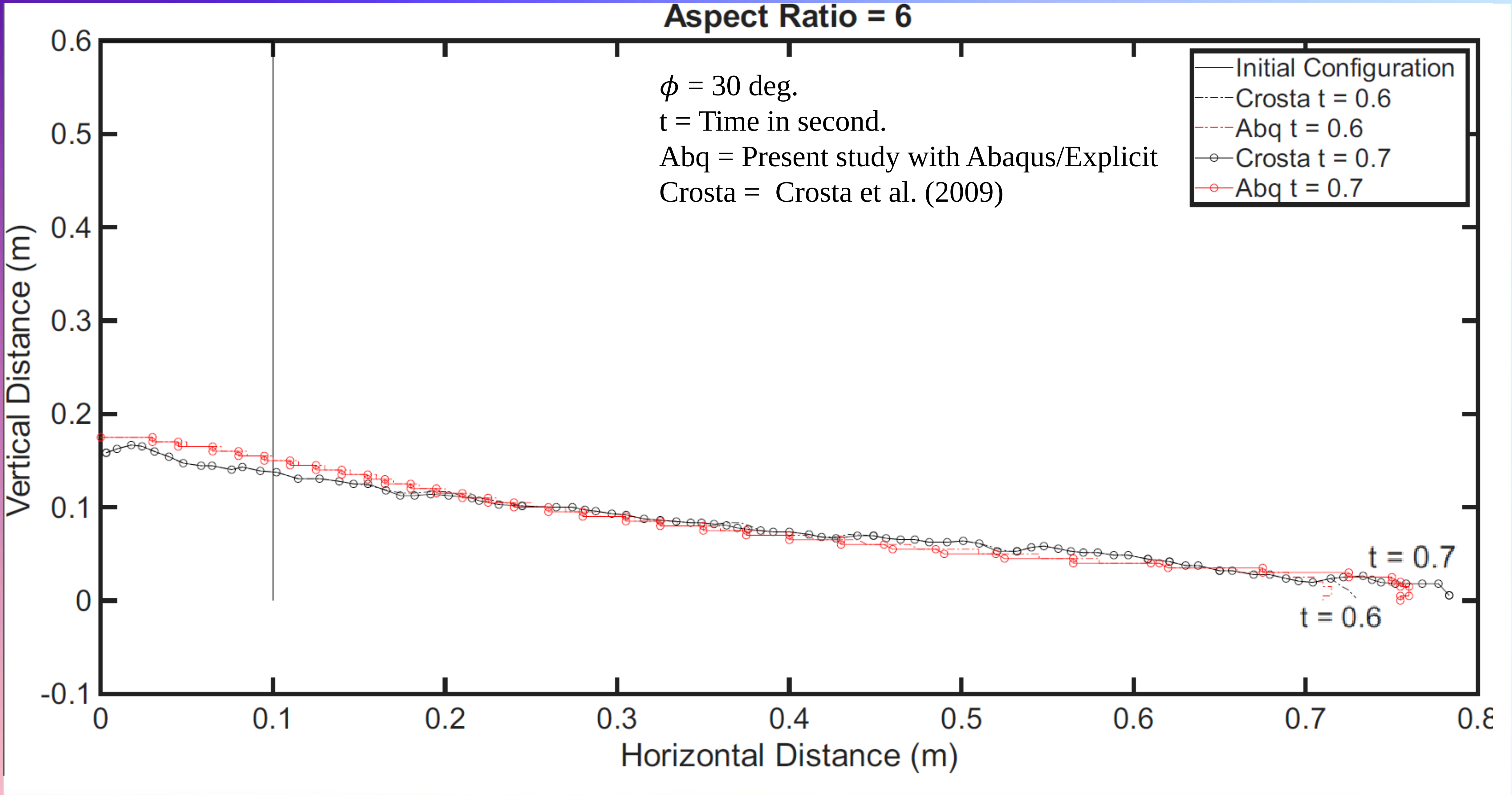

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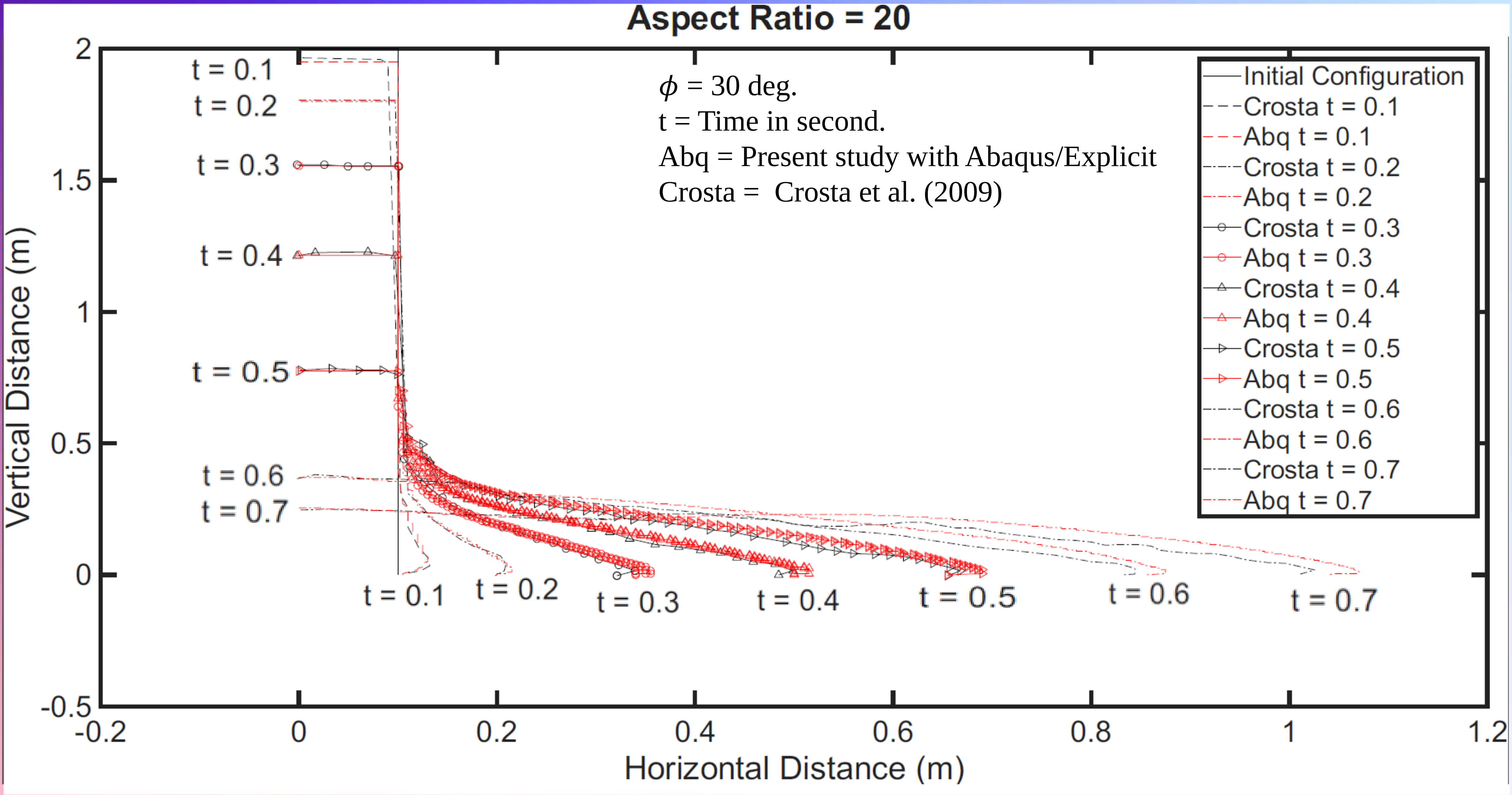

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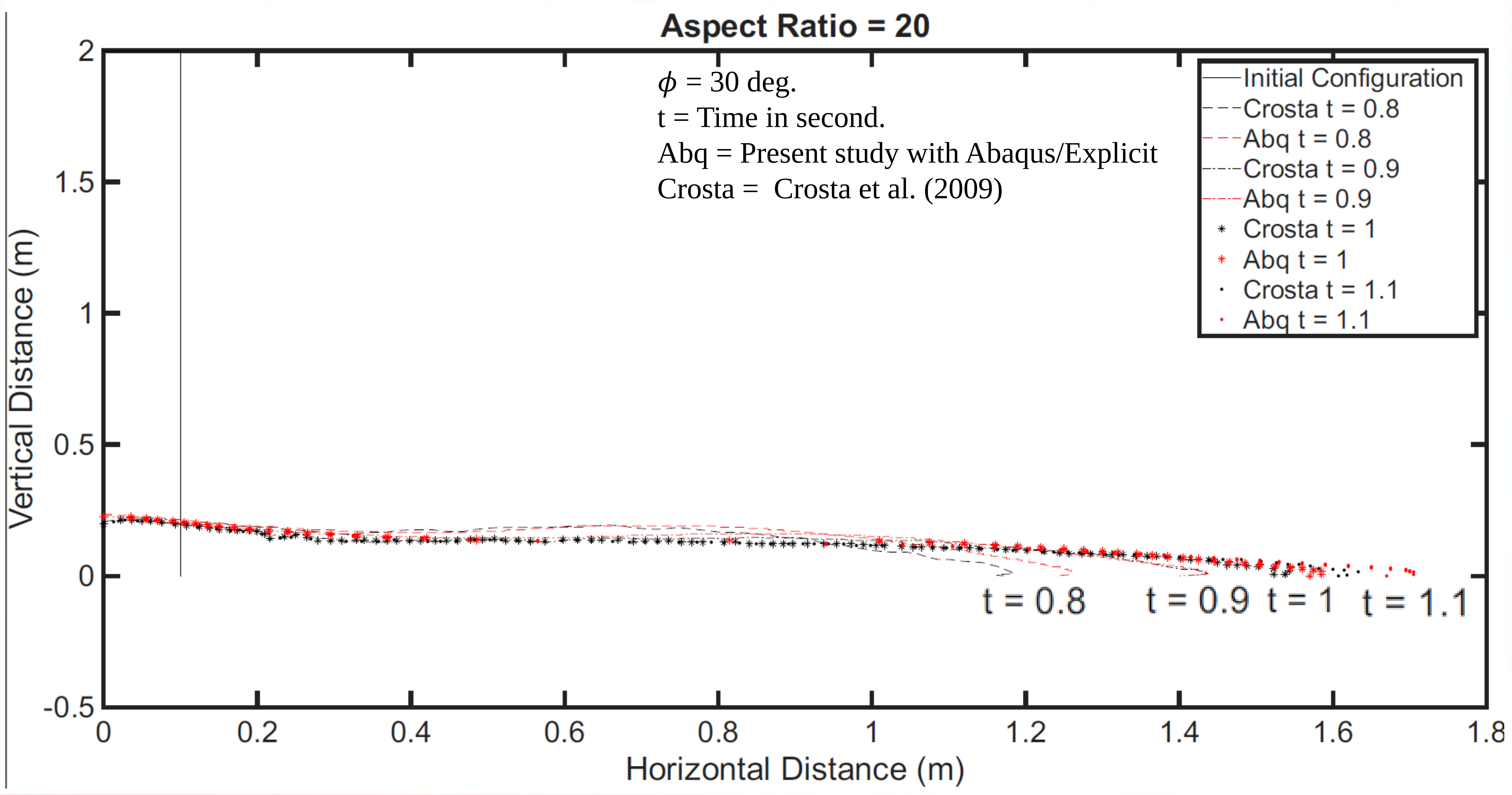

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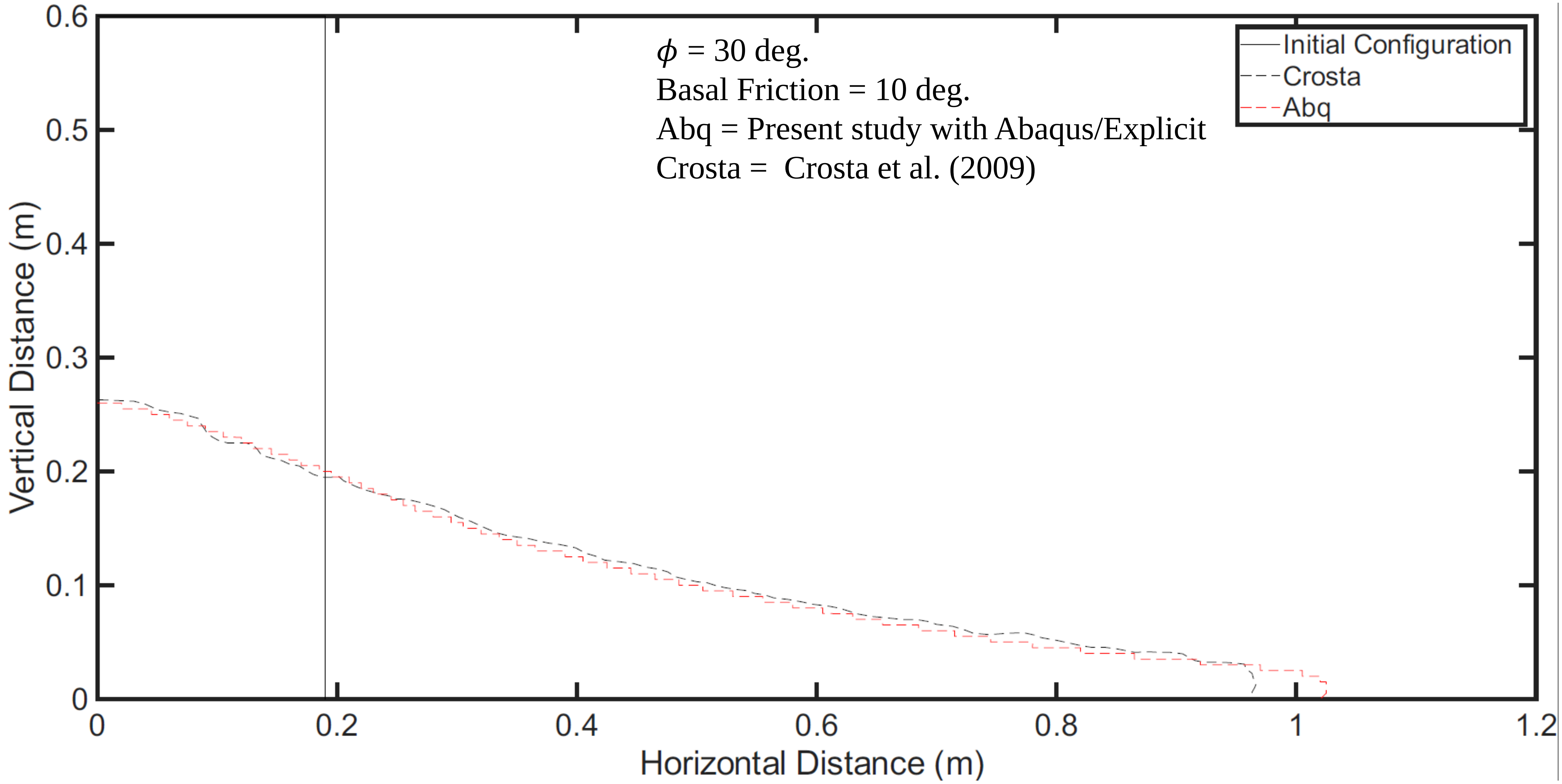
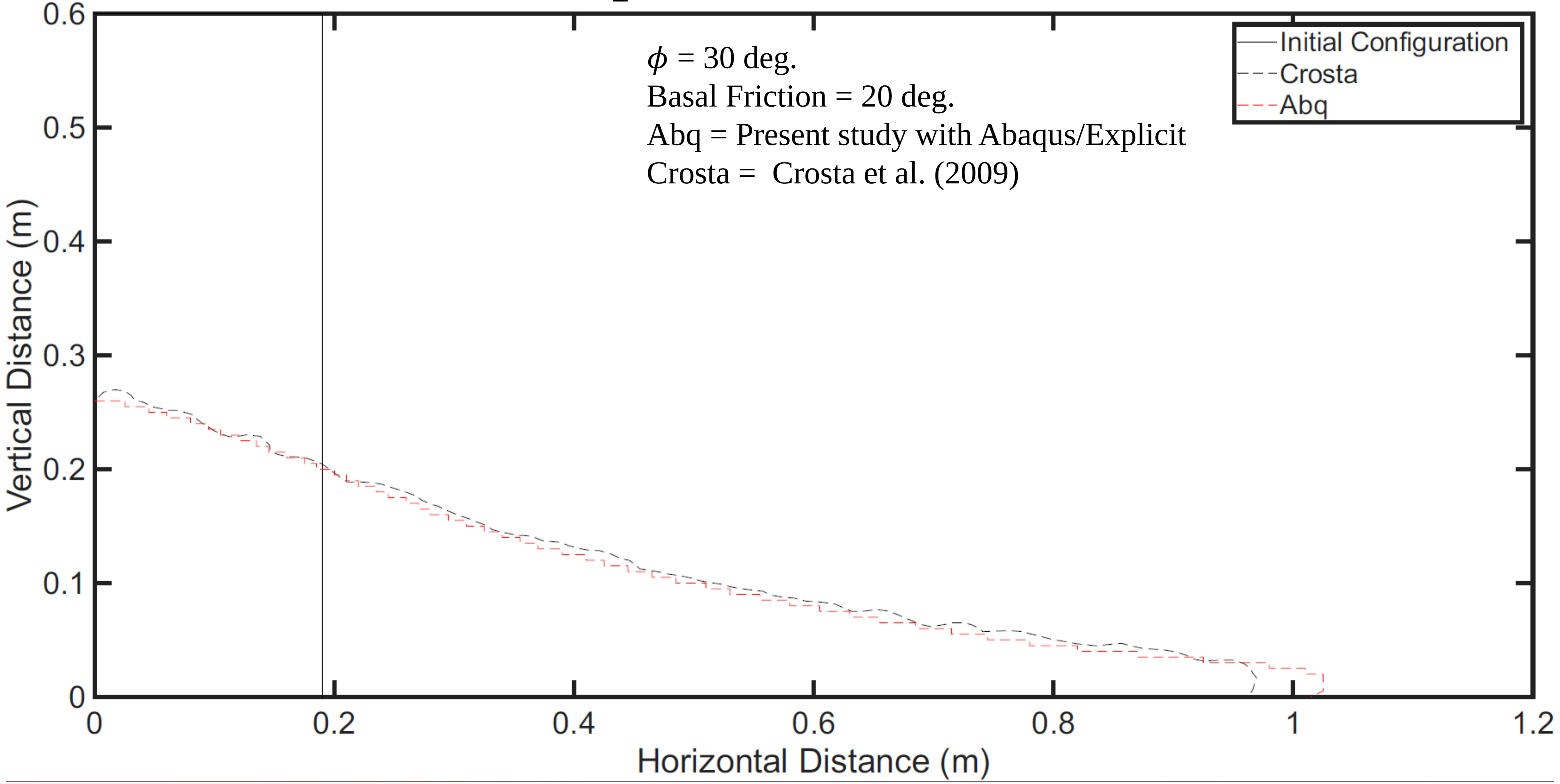
Aspect Ratio = 3.2

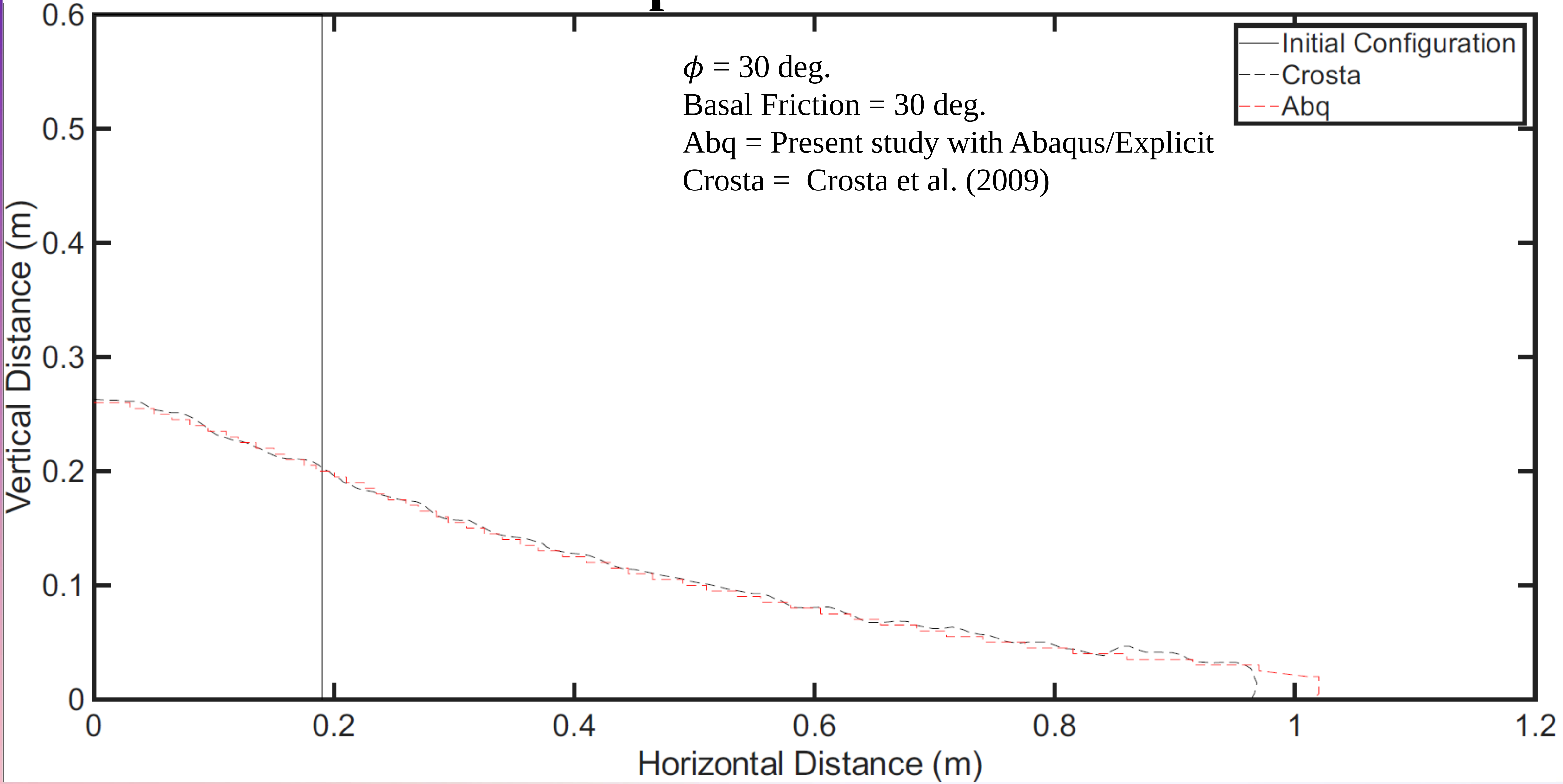


Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Aspect Ratio = 3.2

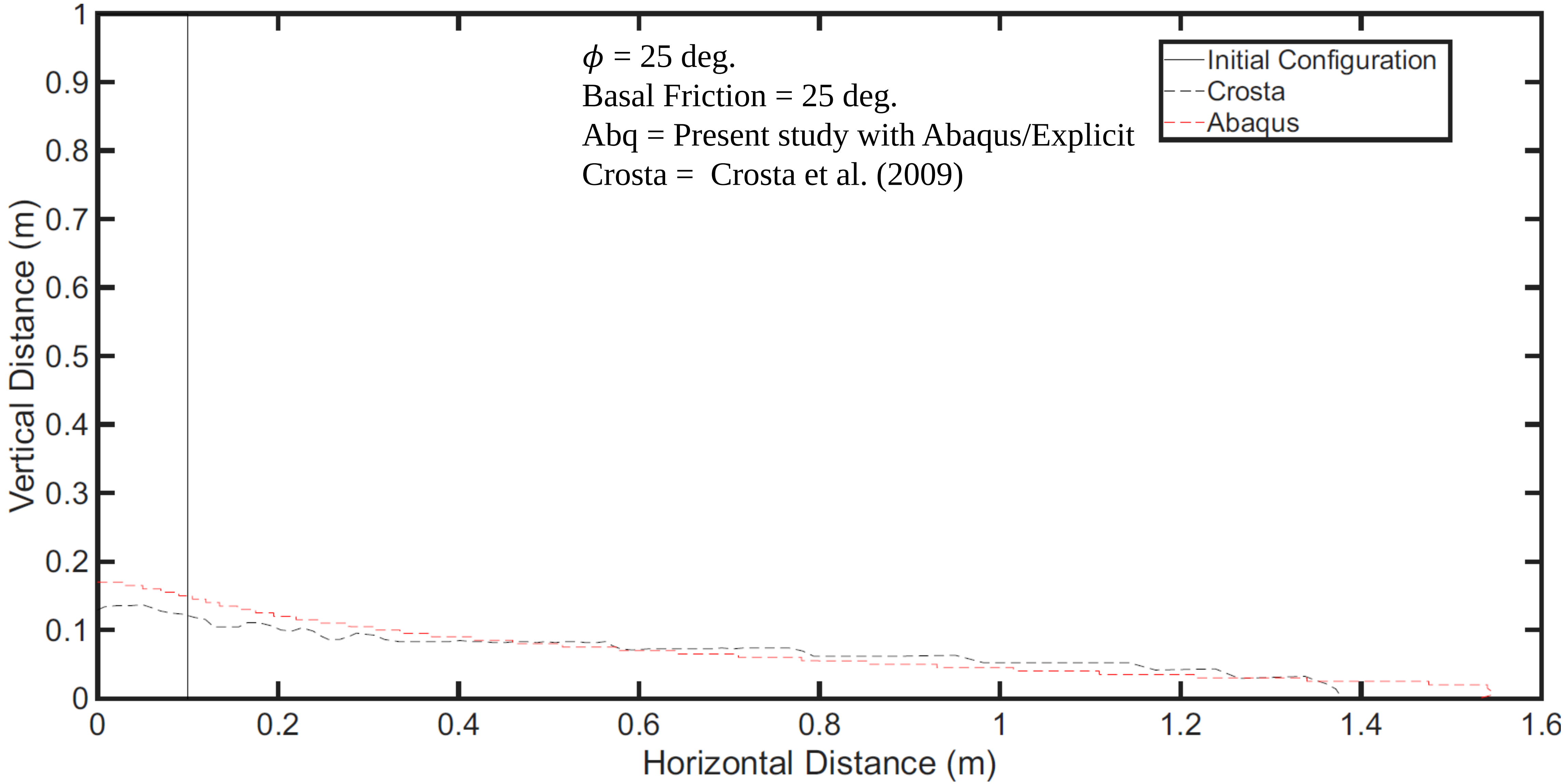


Aspect Ratio = 3.2



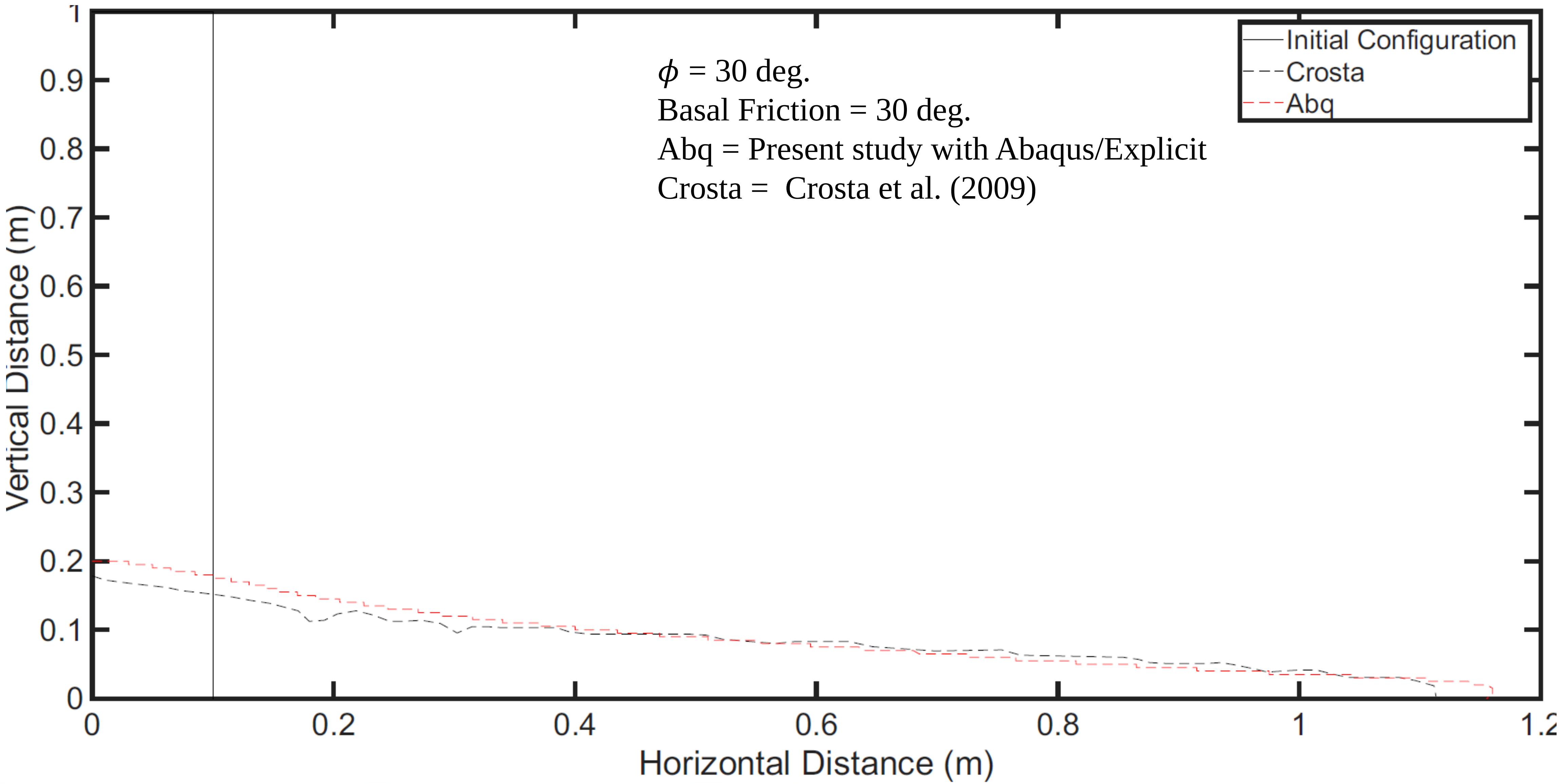
Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Aspect Ratio = 10



Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Aspect Ratio = 10



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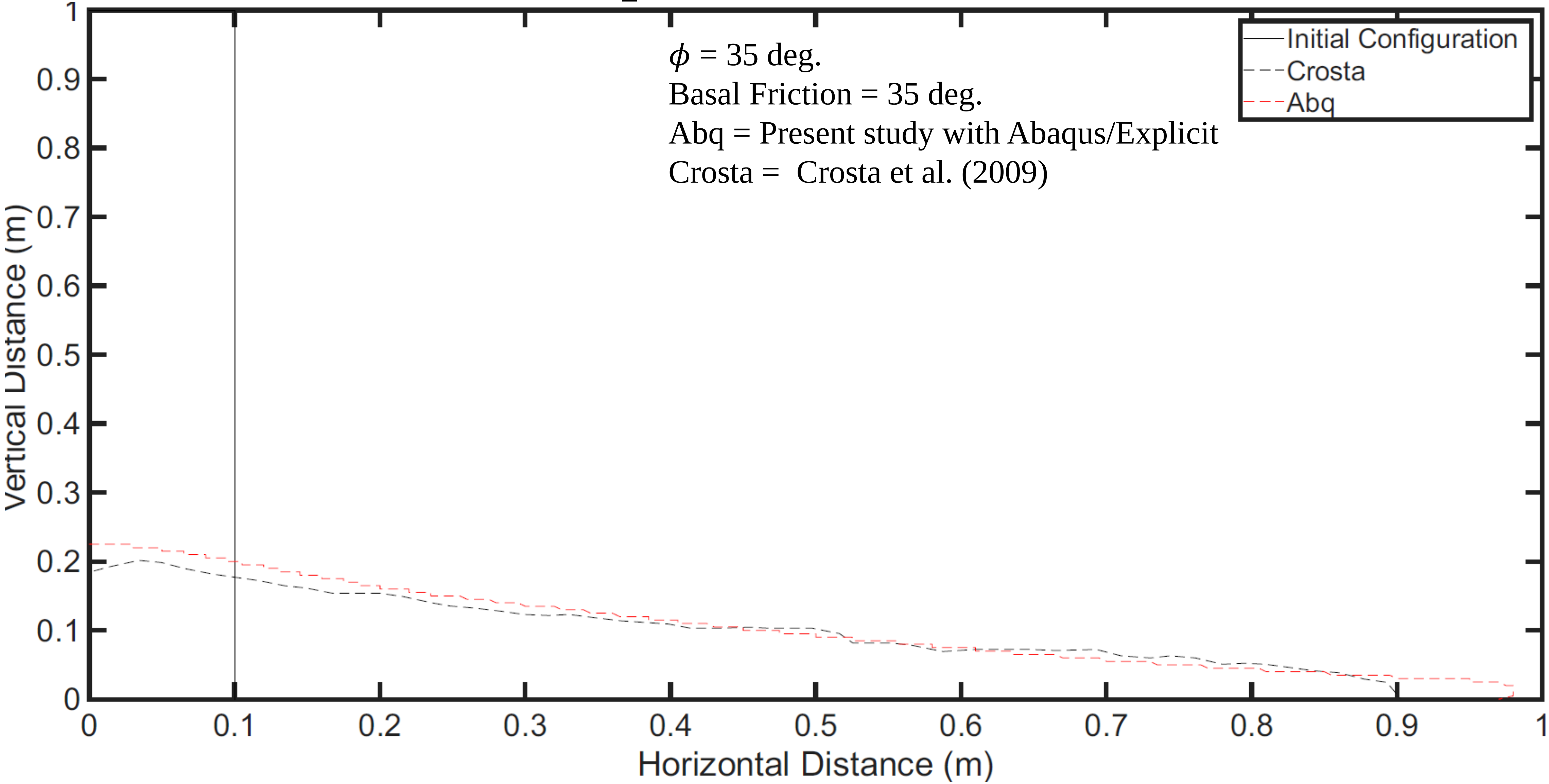
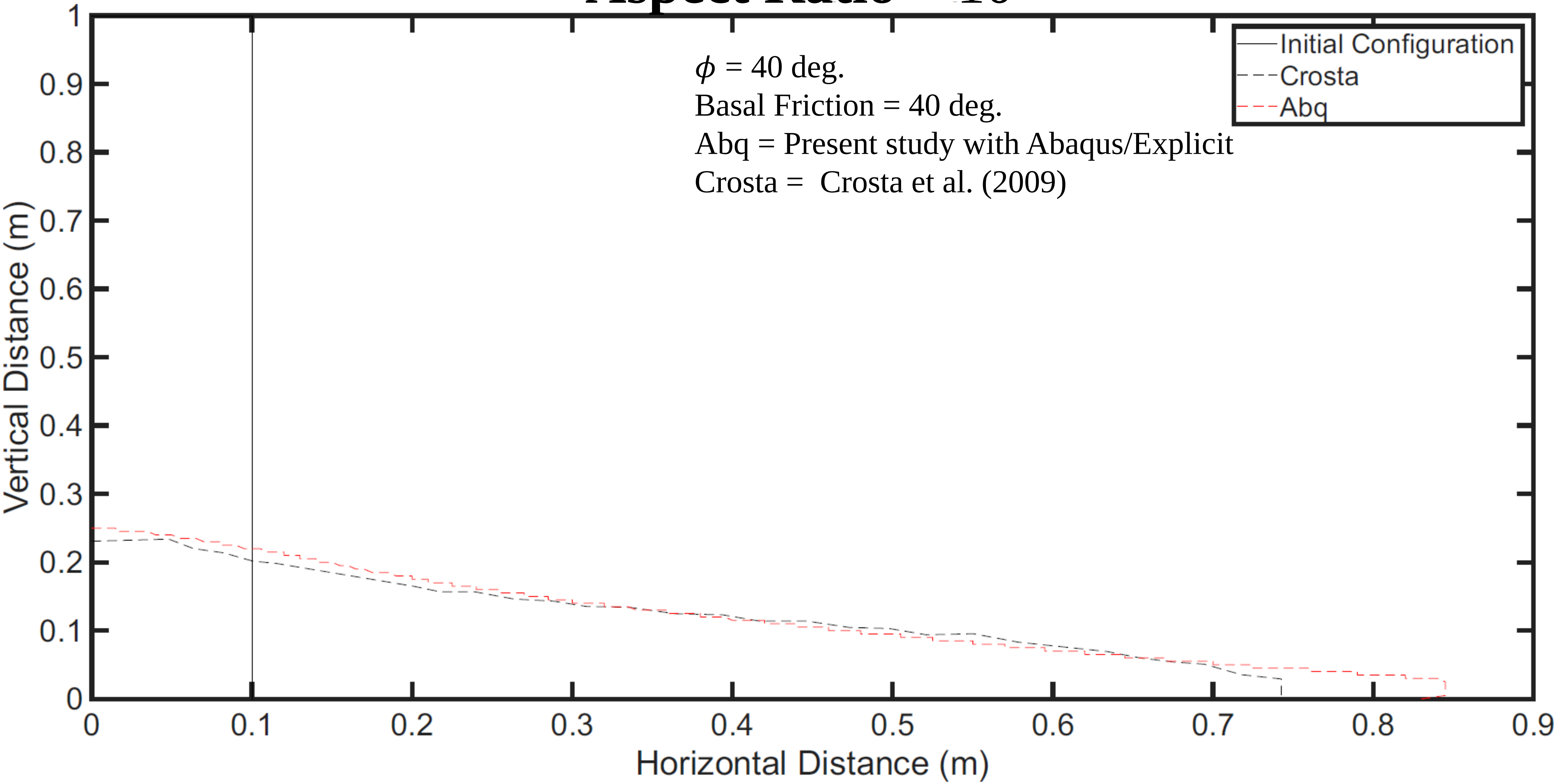
Aspect Ratio = 10



Aspect Ratio = 10



References

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Part B: Scaling Law Results

Modified Granular Bond Number

$$B_o = \frac{ca}{\rho\ g\ H_i} = \frac{ca}{\rho g a L_{ini}} = \frac{c}{\rho g L_{ini}}$$

where

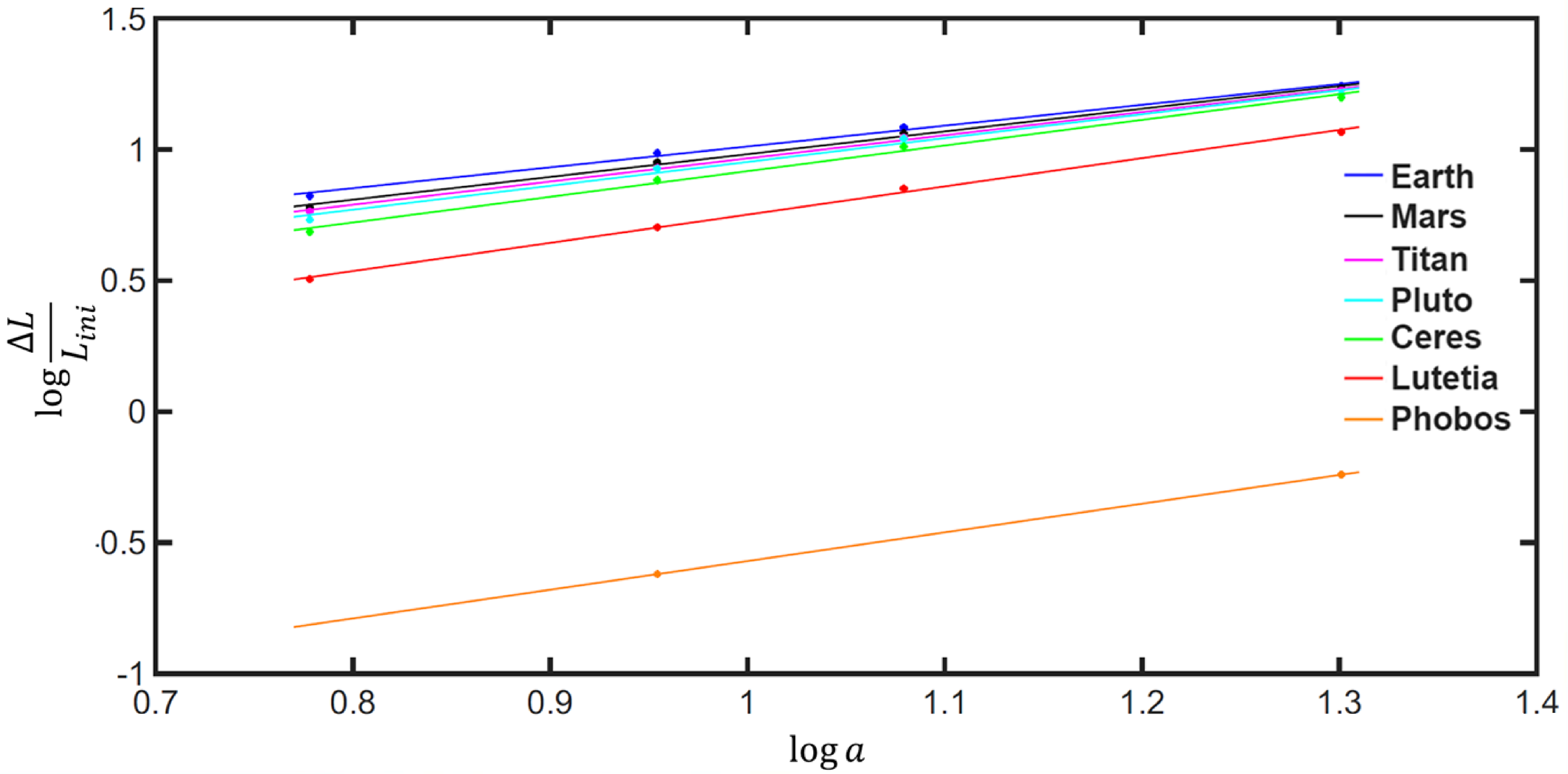
- a is column aspect ratio
- c is Mohr-Coulomb cohesion yield stress
- ρ is density
- g is gravity
- H_i is initial column height
- L_{ini} is initial column length

Type	Gravity (m/s²)	B_o
Planet	Earth (9.81) (g)	6.79×10^{-4}
Planet	Mars (3.72) (0.379g)	1.79×10^{-3}
Moon	Titan (1.35) (0.138g)	4.94×10^{-3}
Dwarf Planet	Pluto (0.62) (0.063g)	0.0108
Dwarf Planet	Ceres (0.28) (0.028g)	0.0238
Main belt asteroid	21 Lutetia (0.048) (0.00489g)	0.1389
Moon	Phobos (0.006) (0.000612g)	1.1111
Comet	81P/Wild2 (0.00034) (0.00003465g)	19.6078
Asteroid	Ryugu (0.00012) (0.0000122g)	55.5556

Normalized Runout Distance vs. Aspect Ratio: Scaling Law

$$\frac{\Delta L}{L_{ini}} = P_1 a^q$$

$$\log\left(\frac{\Delta L}{L_{ini}}\right) = \log P_1 + q \log a$$



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Type	Gravity (m/s²)	B_o	P_1	q
Planet	Earth (9.81) (g)	6.79×10^{-4}	1.6474	0.7945
Planet	Mars (3.72) (0.379g)	1.79×10^{-3}	1.30	0.8674
Moon	Titan (1.35) (0.138g)	4.94×10^{-3}	1.20878761	0.8836
Dwarf Planet	Pluto (0.62) (0.063g)	0.0108	1.1025554	0.9099
Dwarf Planet	Ceres (0.28) (0.028g)	0.0238	0.868	0.9786
Main belt asteroid	21 Lutetia (0.048) (0.00489g)	0.1389	0.4726	1.077
Moon	Phobos (0.006) (0.000612g)	1.1111	0.021677	1.094
Comet	81P/Wild2 (0.00034) (0.00003465g)	19.6078	0	-
Asteroid	Ryugu (0.00012) (0.0000122g)	55.5556	0	-

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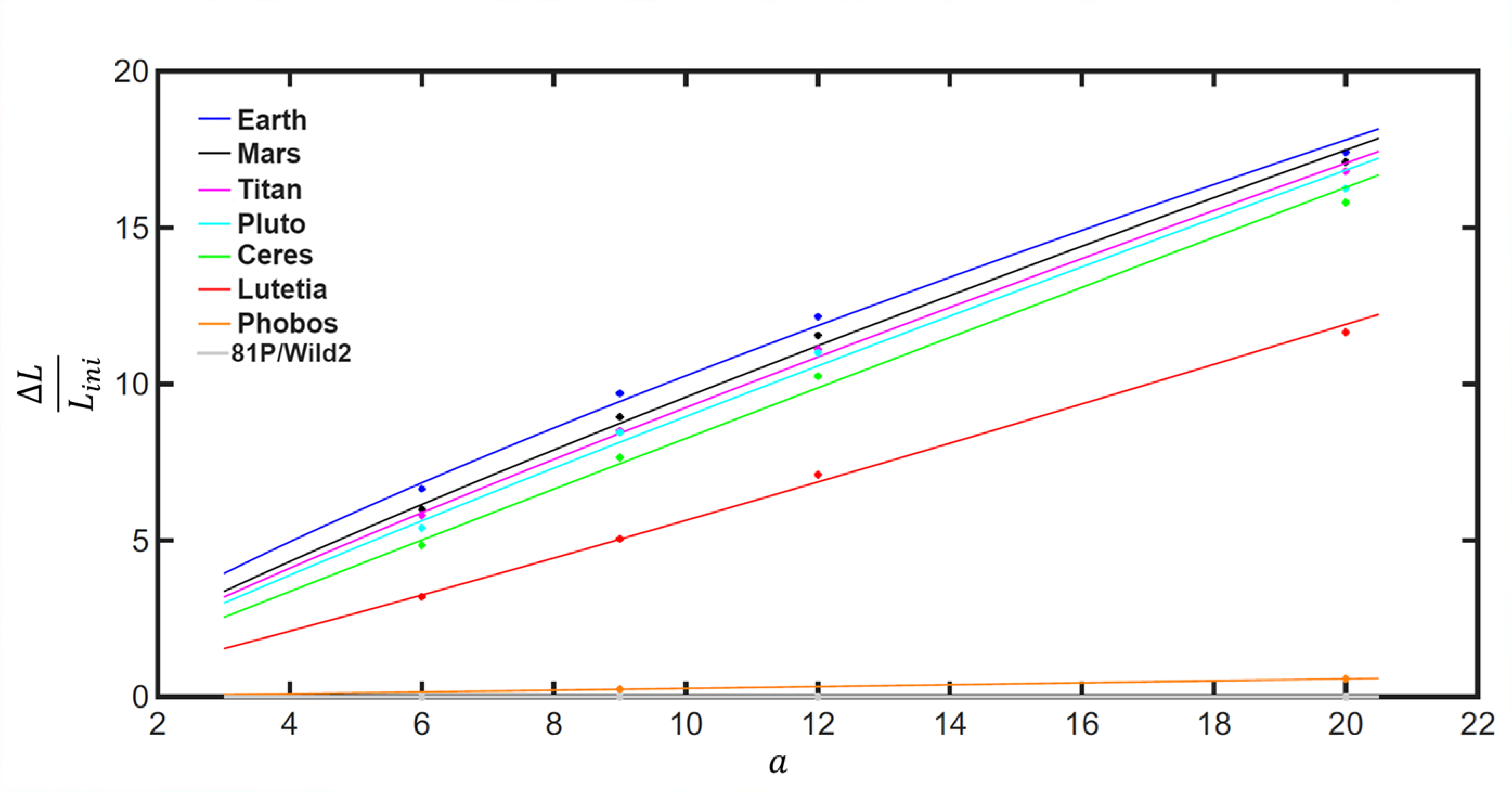

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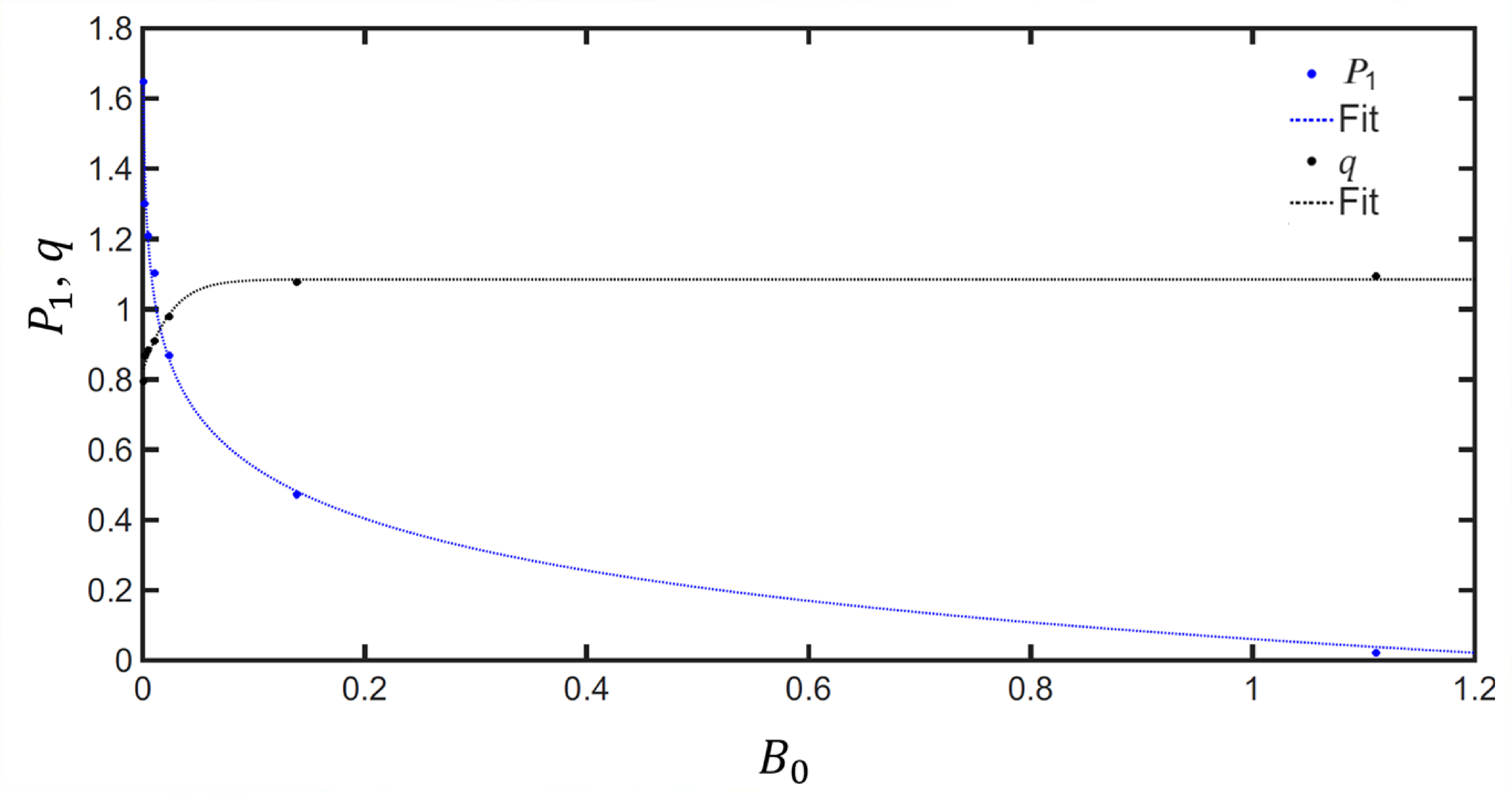


P_1
Fit
q
Fit
P_1, q
B_0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

Scaling Law Modification

$$6 \leq a \leq 20$$

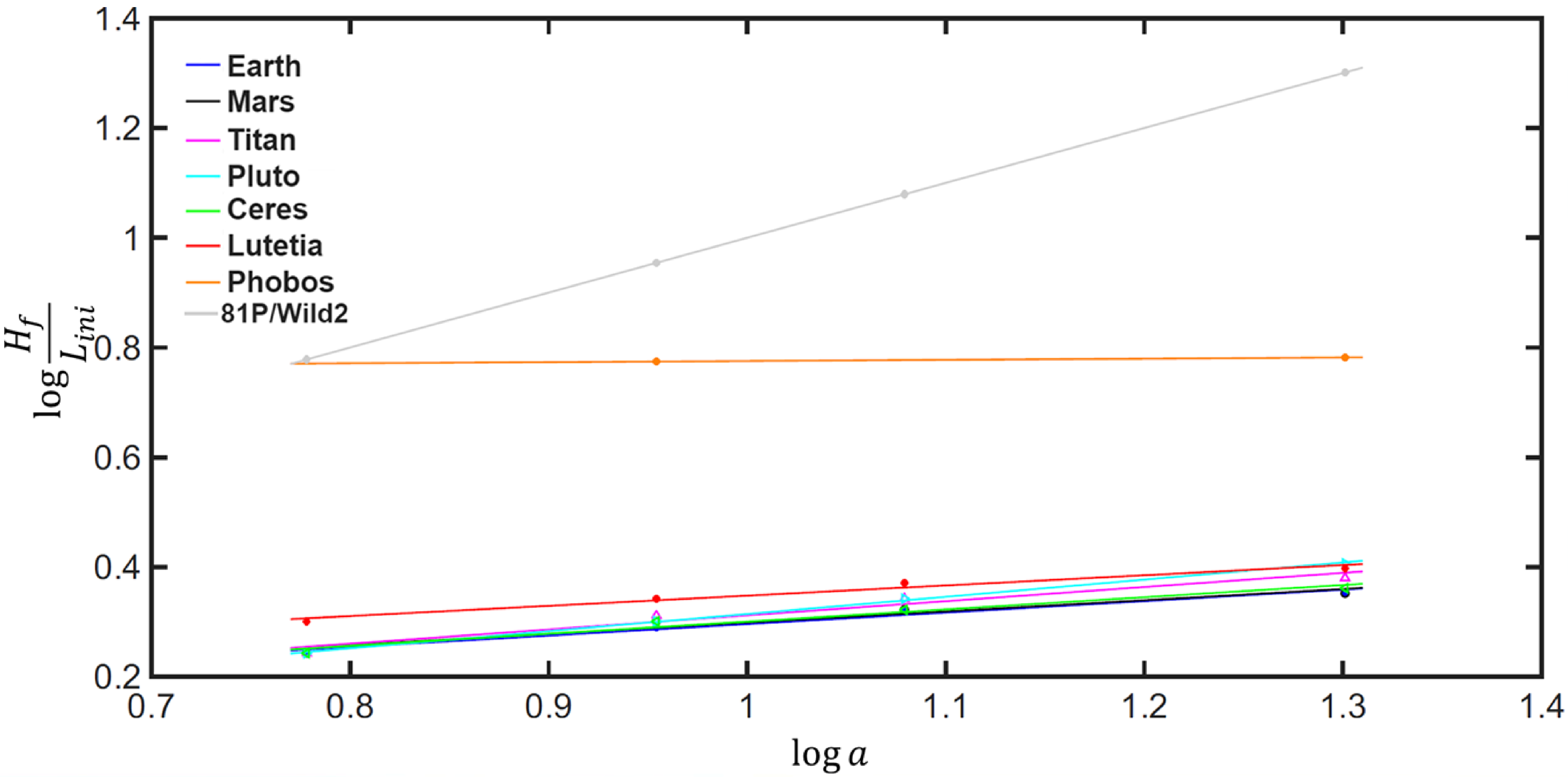
$$\frac{\Delta L}{L_{ini}} = P_1(B_o)a^{q(B_o)}$$

$$\frac{\Delta L}{L_{ini}} = (0.0610 - 0.2131\ln(B_o))a^{\left(\frac{1.0850}{1+\exp(-47.8961(B_o+0.0240))}\right)}$$

Normalized Deposit Height vs. Aspect Ratio: Scaling Law

$$\frac{H_f}{L_{ini}} = P_2 a^r$$

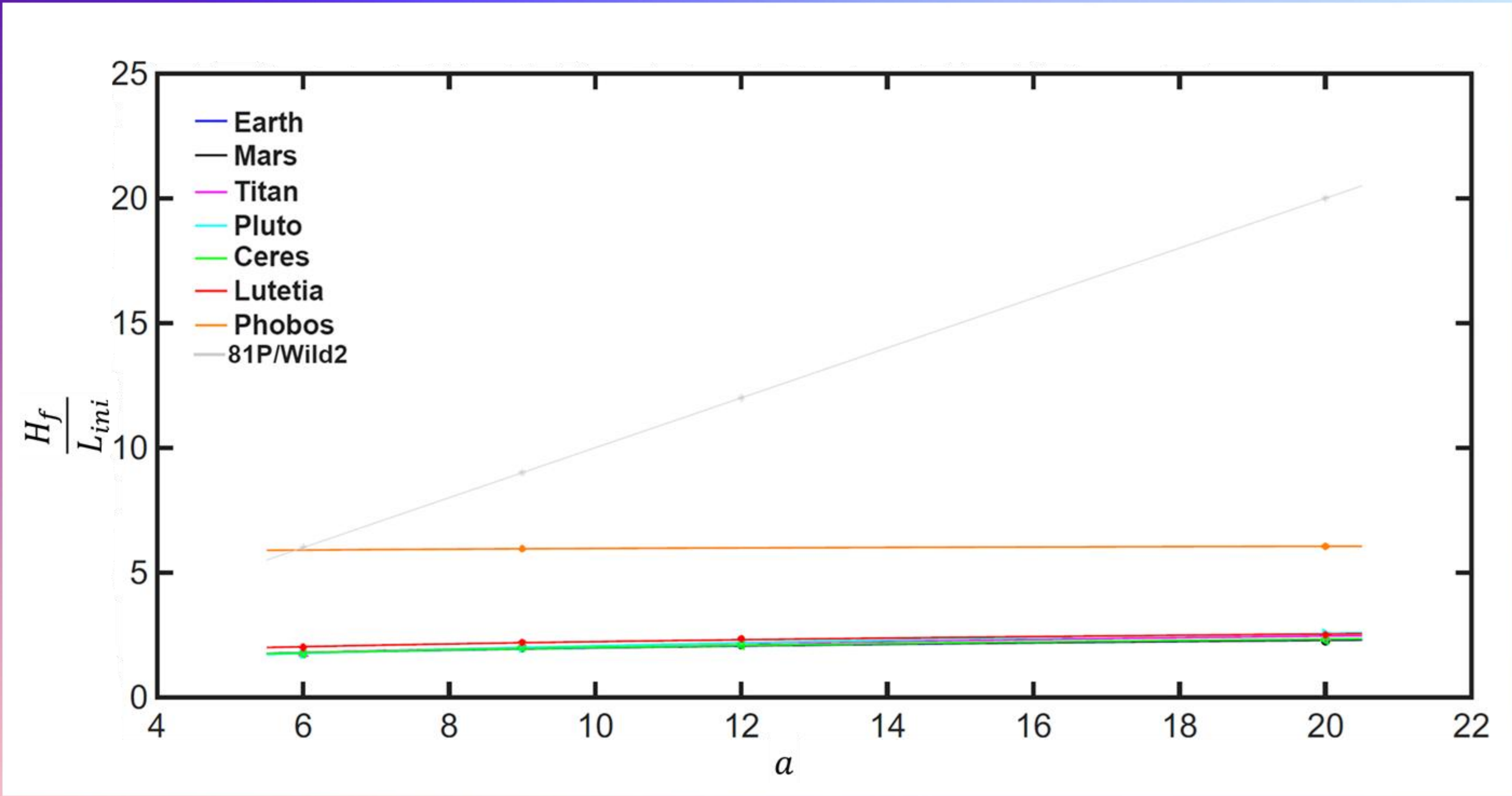
$$\log\left(\frac{H_f}{L_{ini}}\right) = \log P_2 + r \log a$$



Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Type	Gravity (m/s²)	B_o	P_2	r
Planet	Earth (9.81) (g)	6.79×10^{-4}	1.22098	0.2093
Planet	Mars (3.72) (0.379g)	1.79×10^{-3}	1.245145	0.2037
Moon	Titan (1.35) (0.138g)	4.94×10^{-3}	1.13250	0.258
Dwarf Planet	Pluto (0.62) (0.063g)	0.0108	1.0032	0.3131
Dwarf Planet	Ceres (0.28) (0.028g)	0.0238	1.19988	0.2216
Main belt asteroid	21 Lutetia (0.048) (0.00489g)	0.1389	1.452111	0.1859
Moon	Phobos (0.006) (0.000612g)	1.1111	5.68329	0.02087
Comet	81P/Wild2 (0.00034) (0.00003465g)	19.6078	1	1
Asteroid	Ryugu (0.00012) (0.0000122g)	55.5556	-	-

Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32



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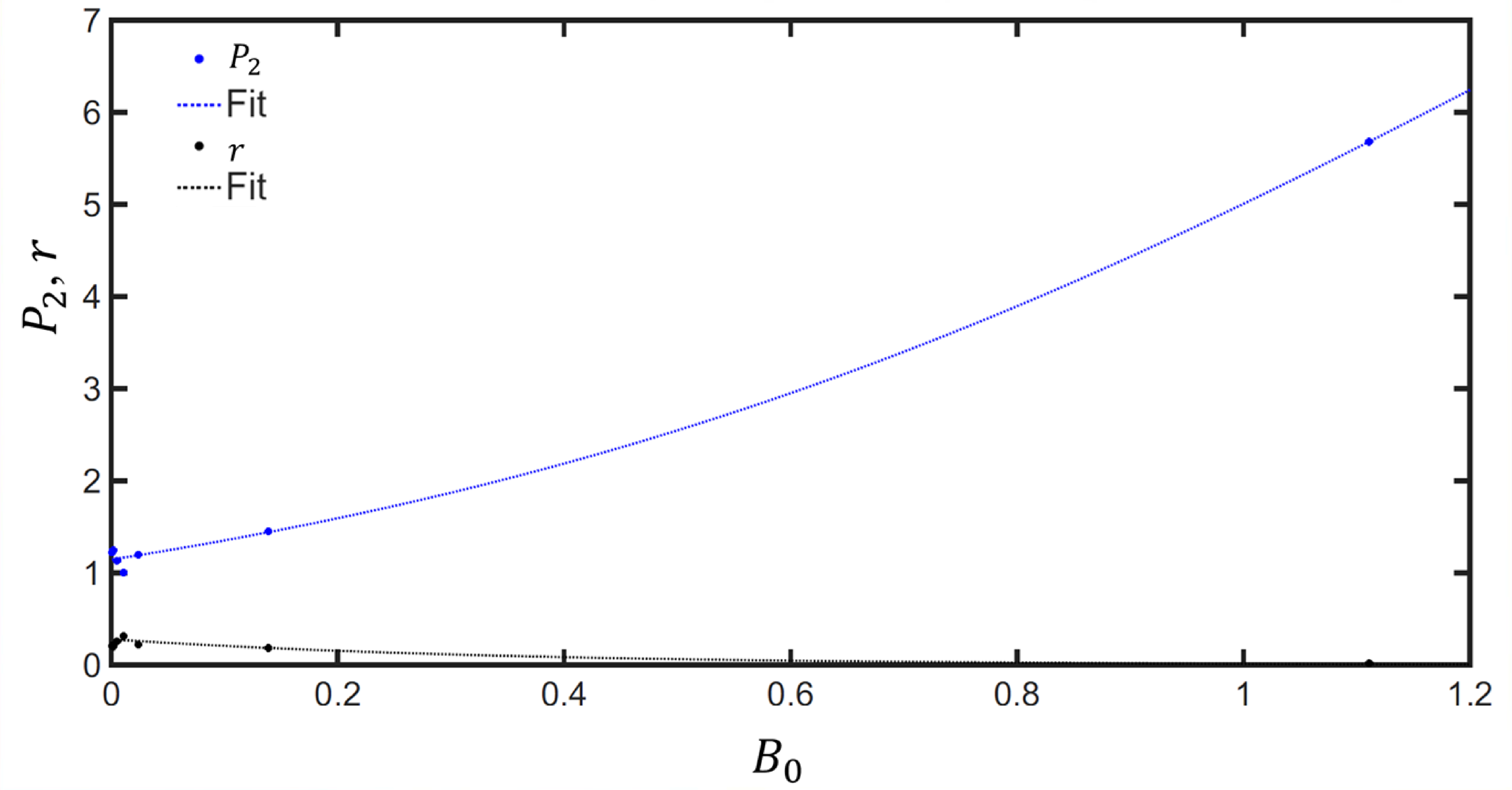


P_2
Fit
r
Fit
P_2, r
B_0
0
1
2
3
4
5
6
7
0
0.2
0.4
0.6
0.8
1
1.2

Scaling Law Modification

$$6 \leq a \leq 20$$

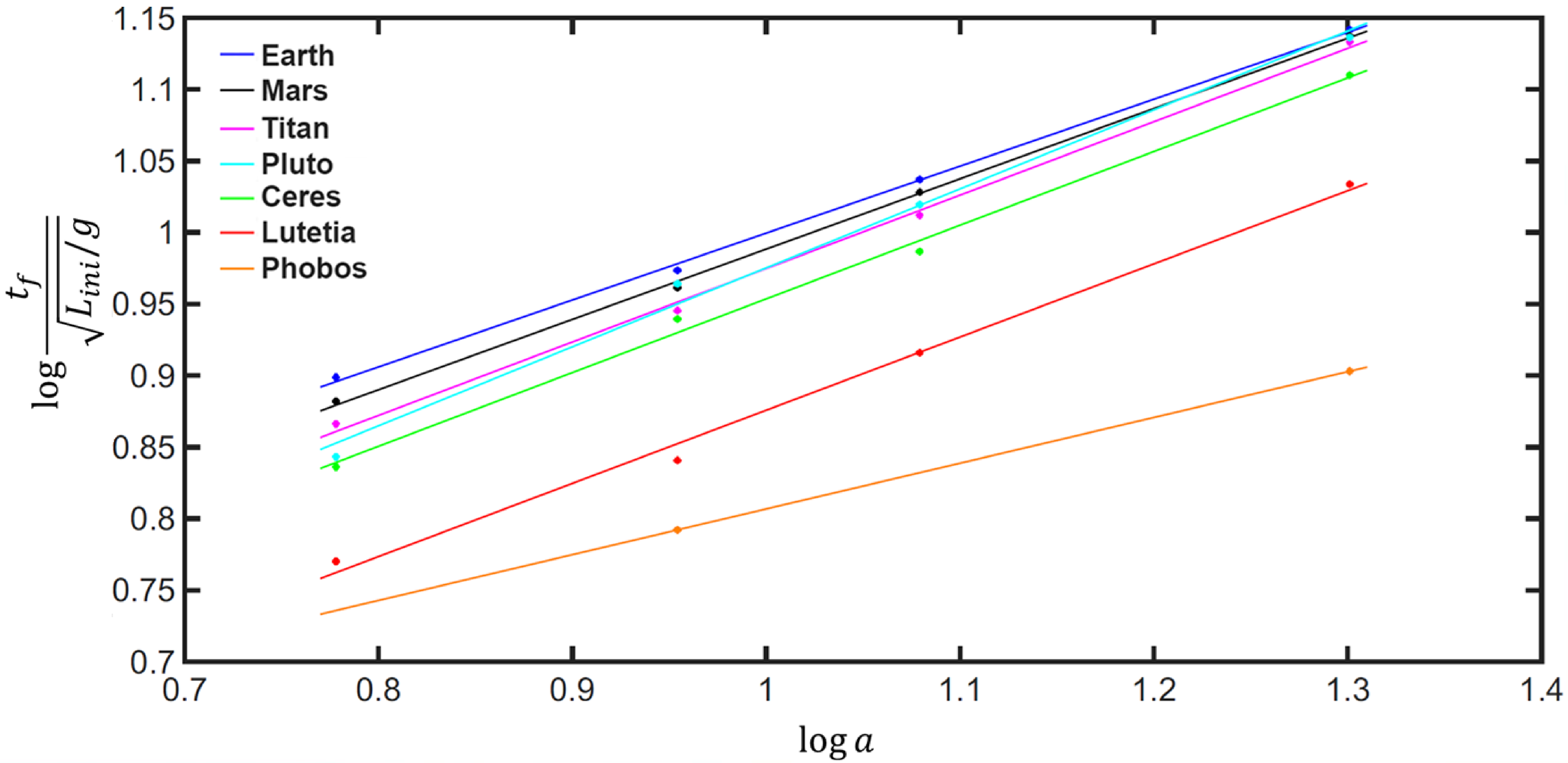
$$\frac{H_f}{L_{ini}} = P_2(B_o) a^{r(B_o)}$$

$$\frac{H_f}{L_{ini}} = \left(\frac{14.2116}{1 + \exp(-1.8252(B_o - 1.3335))}\right) a^{(0.28 \exp(-2.9502 B_o) - 0.1031 \exp(-343.2835 B_o))}$$

Normalized Flow Stop Time vs. Aspect Ratio: Scaling Law

$$\frac{t_f}{\sqrt{\frac{L_{ini}}{g}}} = P_3 a^s$$

$$\log\left(\frac{t_f}{\sqrt{\frac{L_{ini}}{g}}}\right) = \log P_3 + s \log a$$



Poster | Thursday, 10 Sep, 18:00–19:30 (CEST), Display time Thursday, 10 Sep, 08:30–19:30| Foyer 2, F2.32

Type	Gravity (m/s²)	B_o	P_3	s
Planet	Earth (9.81) (g)	6.79×10^{-4}	3.402514	0.4678
Planet	Mars (3.72) (0.379g)	1.79×10^{-3}	3.1397856	0.4915
Moon	Titan (1.35) (0.138g)	4.94×10^{-3}	2.894676	0.5132
Dwarf Planet	Pluto (0.62) (0.063g)	0.0108	2.65033029	0.552
Dwarf Planet	Ceres (0.28) (0.028g)	0.0238	2.744732343	0.5151
Main belt asteroid	21 Lutetia (0.048) (0.00489g)	0.1389	2.31366246	0.5115
Moon	Phobos (0.006) (0.000612g)	1.1111	3.069021988	0.3198
Comet	81P/Wild2 (0.00034) (0.00003465g)	19.6078	-	-
Asteroid	Ryugu (0.00012) (0.0000122g)	55.5556	-	-

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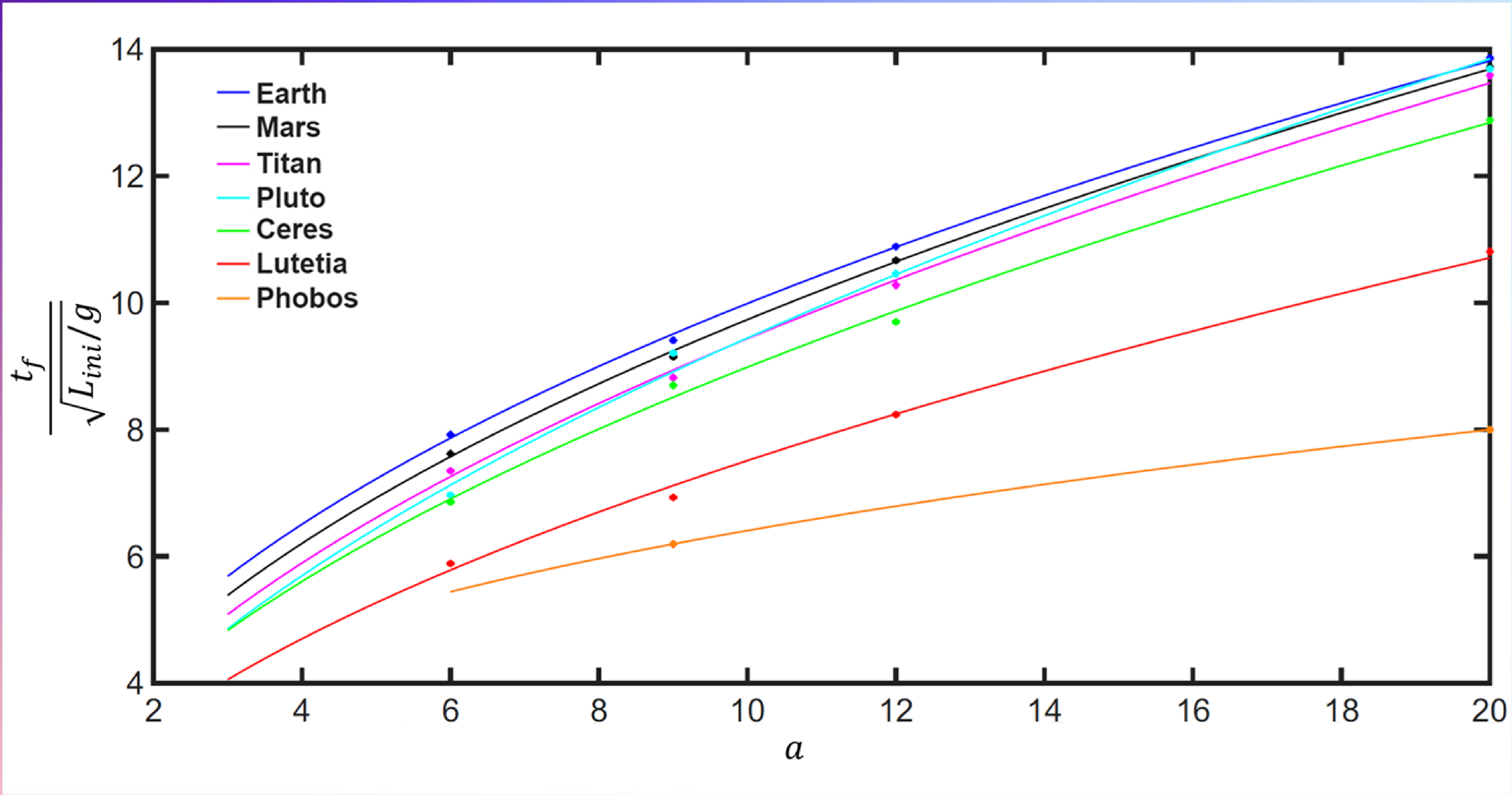

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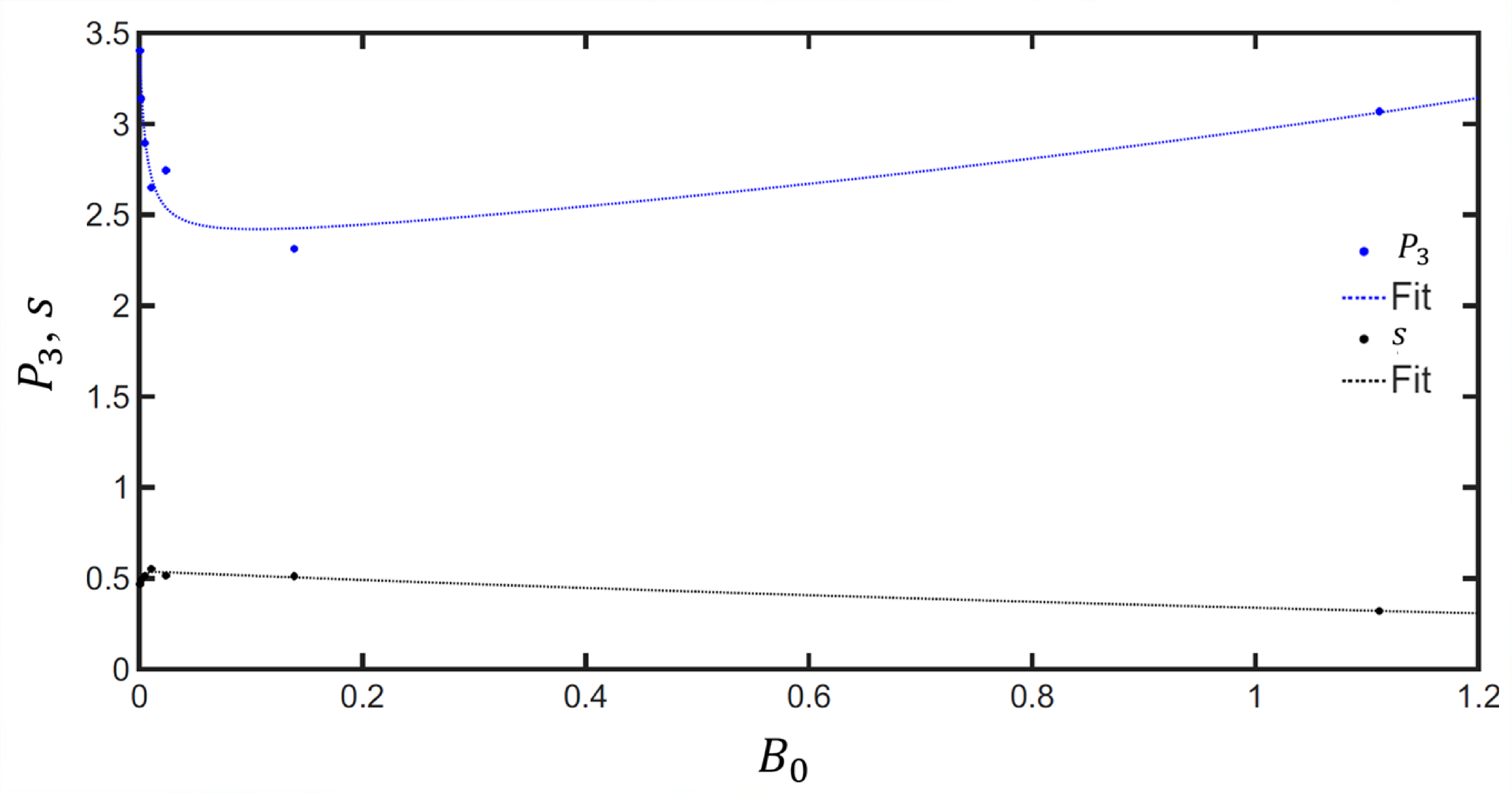

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Scaling Law Modification

$$6 \leq a \leq 20$$

$$\frac{t_f}{\sqrt{\frac{L_{ini}}{g}}} = P_3(B_o)a^{s(B_o)}$$

$$\frac{t_f}{\sqrt{\frac{L_{ini}}{g}}} = \left(\frac{-10.4663B_o \ - 0.087}{{B_o}^2 - 4.5317B_o \ - 0.025}\right)a^{(0.5391 \exp(-0.4676B_o) - 0.089 \exp(-332.9256 \ B_o))}$$