Examination of C82 Configuration

C. Kessel
10/14/99

- would like to make $\{R_{mn}, Z_{mn}\}$ the minimum required for the plasma configuration by keeping (m,n) small

- inferring that this will correspond to a minimum $\{B_{mn}\}$ (or at least reduced) for the equilibrium

  → keep equilibrium field requirements corresponding to physically realizable plasma boundary changes ($\gtrsim$ 1 cm.) and iota changes

  → ease coil requirements by removing high order (high m,n) fields

  → avoid introduction of lots of high (m,n) equilibrium fields that resonate with $\iota(s)$ to produce seed islands / and may not be easy to distinguish from field pollution introduced by "real" coils

- eliminated entire toroidal or poloidal mode numbers and examined maximum boundary deviation & kink growth rate

$R_{m,n} = Z_{mn} = 0$ $\quad \lambda_K^{C82} = -.18 \times 10^{-4}$

* $m = 5$ $\quad \Delta_{max} = 4.3$ mm $\quad \lambda_K = -.3 \times 10^{-3}$

$m = 4,5$ $\quad \Delta_{max} = 9.5$ mm $\quad \lambda_K = -.45 \times 10^{-3}$

$m = 3,4,5$ $\quad \Delta_{max} = 40.0$ mm $\quad \lambda_K = -.2 \times 10^{-2}$

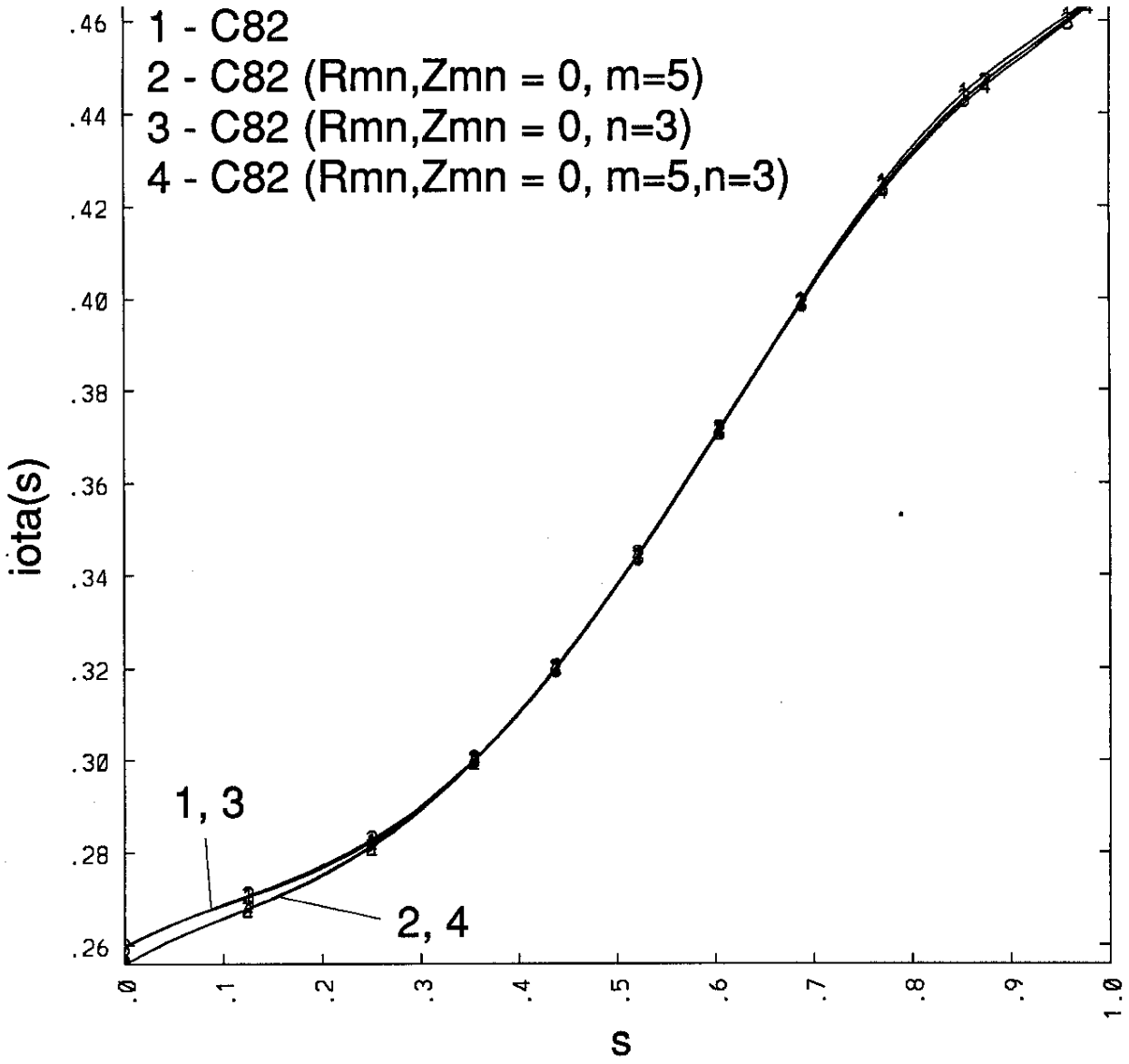
* $n = 3$ $\quad \Delta_{max} = 6.2$ mm $\quad \lambda_K = -.86 \times 10^{-4}$

$n = 2,3$ $\quad \Delta_{max} = 64.0$ mm $\quad \lambda_K = -.18 \times 10^{-2}$

* $n = 3, m = 5$ $\quad \Delta_{max} = 9.9$ mm $\quad \lambda_K = -.36 \times 10^{-3}$

→ how is the optimizer using these higher (m,n) shape terms, QA??

→ can we rely on shape terms (and the corresponding B_{mn}'s) that amount to millimeter deformations of the plasma boundary / and very small changes in iota. to obtain a desirable property of the equilibrium?

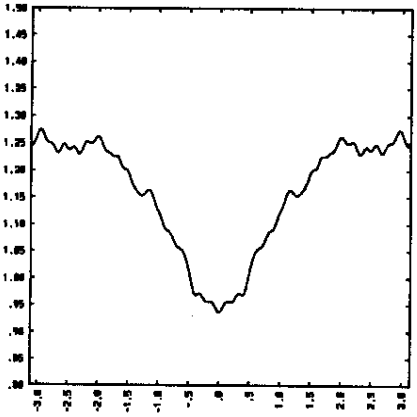

1 - C82
2 - C82 (Rmn,Zmn = 0, m=5)
3 - C82 (Rmn,Zmn = 0, n=3)
4 - C82 (Rmn,Zmn = 0, m=5,n=3)
1, 3
2, 4
iota(s)
s
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

(4)

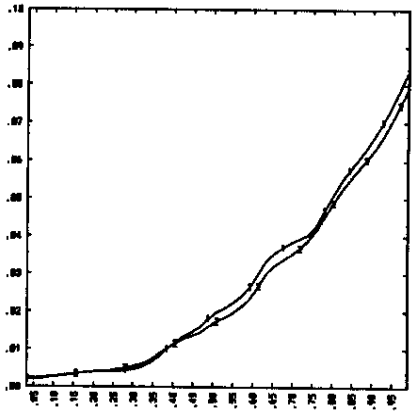
s= 0.55

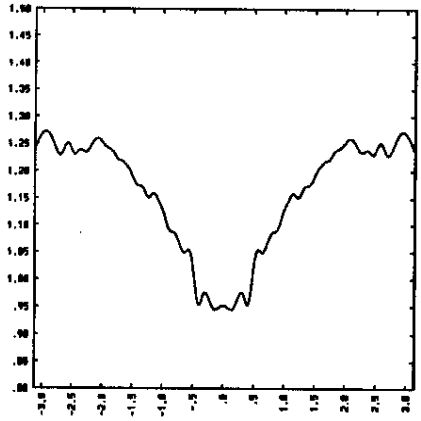
C82

ripple area

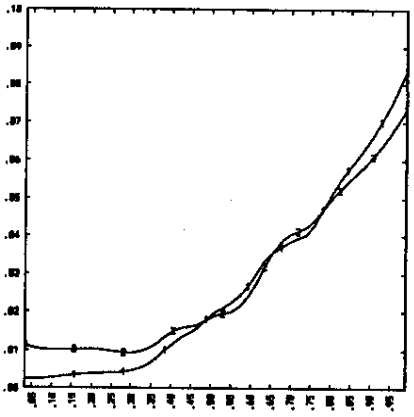


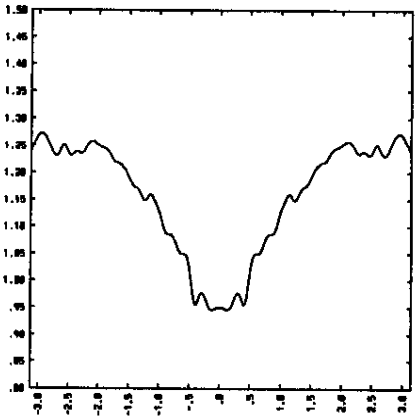
C82
(Rmn,Zmn=0)
m=5



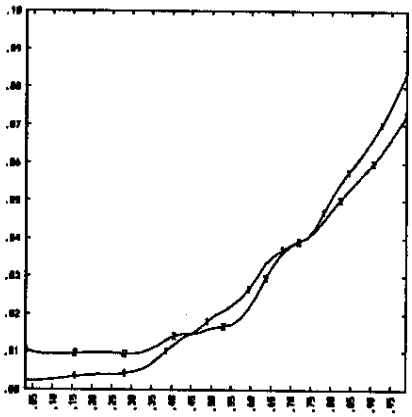


C82
(Rmn,Zmn=0)
n=3





C82
(Rmn,Zmn=0)
m=5,n=3



θ

s

- eliminated $\{R_{mn}, Z_{mn}\}$ shape terms by magnitude

terms with values $1\times10^{-6} - 9.99\times10^{-6}$ $\Delta_{max} = .006$ mm

$1\times10^{-5} - 9.99\times10^{-5}$ $\Delta_{max} = .24$ mm

$1\times10^{-4} - 9.99\times10^{-4}$ $\Delta_{max} = 3.8$ mm

$1\times10^{-3} - 9.99\times10^{-3}$ $\Delta_{max} = 58$ mm.

$\lambda_K = -.4\times10^{-5}$ $\left(\lambda_K^{C82} = -.18\times10^{-4}\right)$

refer to this case as C82-mod

→ the shape terms that are eliminated appear to smear out ripple wells, but have a worse impact on kink instability

→ the boundary deformation is small and the iota profiles are nearly identical between C82 and C82-mod

→ is the optimizer using these terms to obtain some equilibrium property ??

RBC(0,0) =	1.4229E+00	ZBS(0,0) =	0.0000E+00
RBC(1,0) =	-7.8029E-02	ZBS(1,0) =	4.0426E-02
RBC(2,0) =	9.8286E-03	ZBS(2,0) =	3.1820E-03
RBC(3,0) =	3.2375E-03	ZBS(3,0) =	1.4279E-03
RBC(-3,1) =	0.0000E-05	ZBS(-3,1) =	0.0000E-05
RBC(-2,1) =	-3.8732E-03	ZBS(-2,1) =	-1.2195E-02
RBC(-1,1) =	5.8520E-03	ZBS(-1,1) =	1.3840E-02
RBC(0,1) =	3.1680E-01	ZBS(0,1) =	6.0177E-01
RBC(1,1) =	-7.0925E-02	ZBS(1,1) =	9.0617E-02
RBC(2,1) =	4.1415E-03	ZBS(2,1) =	-2.0210E-02
RBC(3,1) =	0.0000E-04	ZBS(3,1) =	-0.0000E-04
RBC(-3,2) =	-1.3950E-03	ZBS(-3,2) =	-1.5776E-03
RBC(-2,2) =	-2.0886E-03	ZBS(-2,2) =	-1.4529E-03
RBC(-1,2) =	4.1121E-02	ZBS(-1,2) =	5.4145E-02
RBC(0,2) =	7.1435E-02	ZBS(0,2) =	6.3807E-03
RBC(1,2) =	1.2603E-01	ZBS(1,2) =	-2.7382E-02
RBC(2,2) =	1.0068E-03	ZBS(2,2) =	-1.0387E-02
RBC(3,2) =	0.0000E-04	ZBS(3,2) =	0.0000E-03
RBC(-3,3) =	-0.0000E-04	ZBS(-3,3) =	0.0000E-04
RBC(-2,3) =	-0.0000E-04	ZBS(-2,3) =	0.0000E-04
RBC(-1,3) =	3.9855E-03	ZBS(-1,3) =	-4.0841E-03
RBC(0,3) =	2.6619E-03	ZBS(0,3) =	-6.1801E-03
RBC(1,3) =	1.0829E-02	ZBS(1,3) =	-1.2824E-02
RBC(2,3) =	-2.0140E-02	ZBS(2,3) =	2.0441E-02
RBC(3,3) =	1.5741E-03	ZBS(3,3) =	-1.5626E-03
RBC(-3,4) =	0.0000E-06	ZBS(-3,4) =	0.0000E-06
RBC(-2,4) =	-0.0000E-05	ZBS(-2,4) =	-0.0000E-05
RBC(-1,4) =	-0.0000E-04	ZBS(-1,4) =	-0.0000E-04
RBC(0,4) =	2.0330E-03	ZBS(0,4) =	2.0330E-03
RBC(1,4) =	4.7942E-03	ZBS(1,4) =	4.7942E-03
RBC(2,4) =	0.0000E-04	ZBS(2,4) =	0.0000E-04
RBC(3,4) =	-0.0000E-05	ZBS(3,4) =	-0.0000E-05
RBC(-3,5) =	-0.0000E-05	ZBS(-3,5) =	-0.0000E-05
RBC(-2,5) =	-0.0000E-05	ZBS(-2,5) =	-0.0000E-05
RBC(-1,5) =	0.0000E-04	ZBS(-1,5) =	0.0000E-04
RBC(0,5) =	0.0000E-04	ZBS(0,5) =	0.0000E-04
RBC(1,5) =	1.5327E-03	ZBS(1,5) =	1.5327E-03
RBC(2,5) =	-2.6296E-03	ZBS(2,5) =	-2.6296E-03
RBC(3,5) =	0.0000E-04	ZBS(3,5) =	0.0000E-04

m = 0

m = 1

m = 2

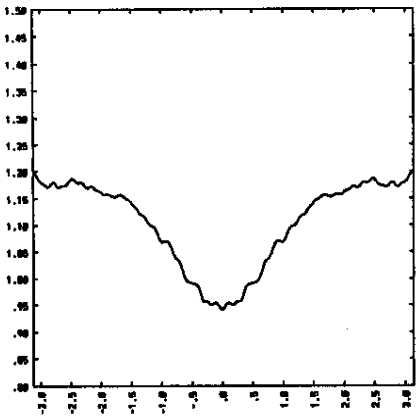
m = 3

m = 4

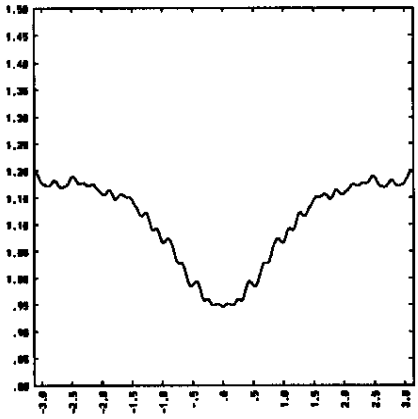
m = 5

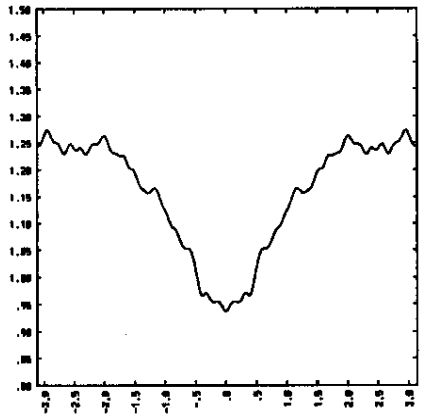
C82 - mod $\{R_{mn}, Z_{mn}\}$

C82 C82-mod

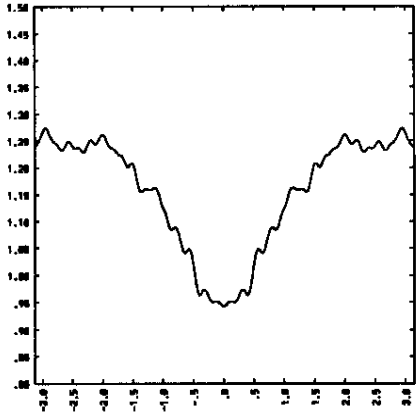


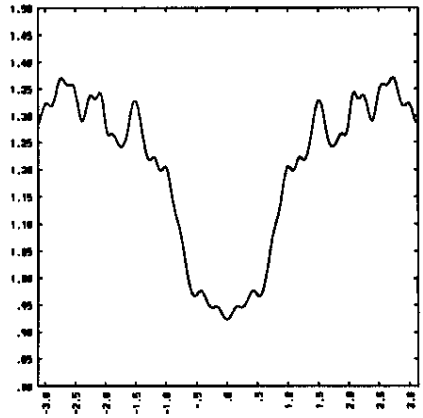
s=0.34



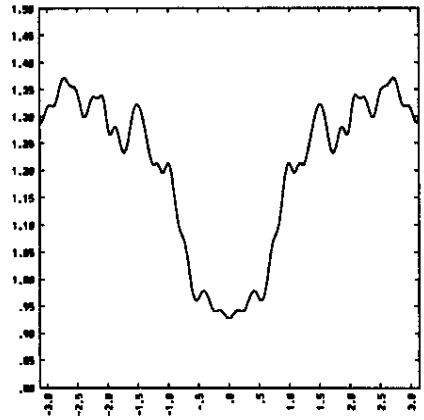


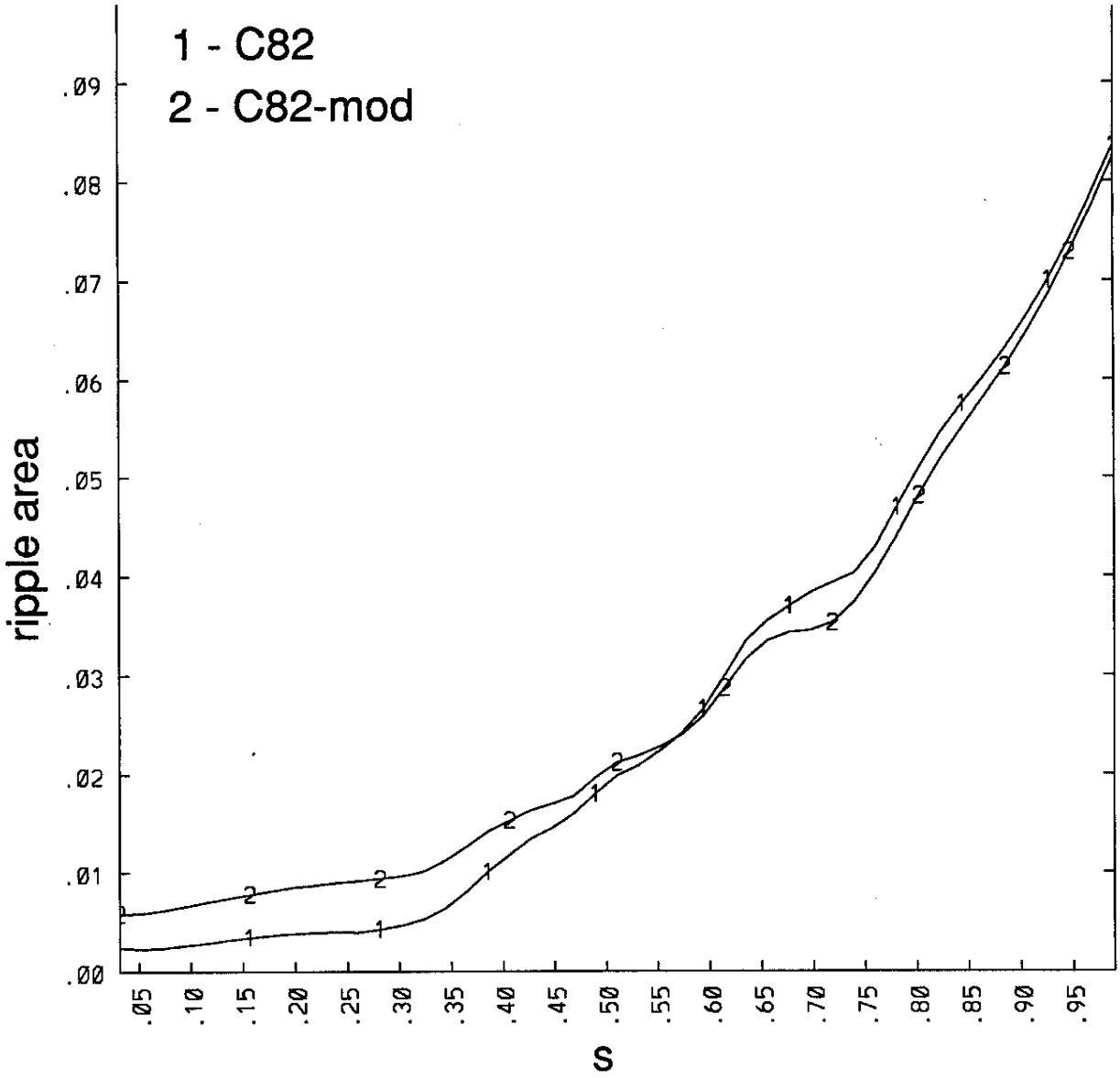
s=0.55

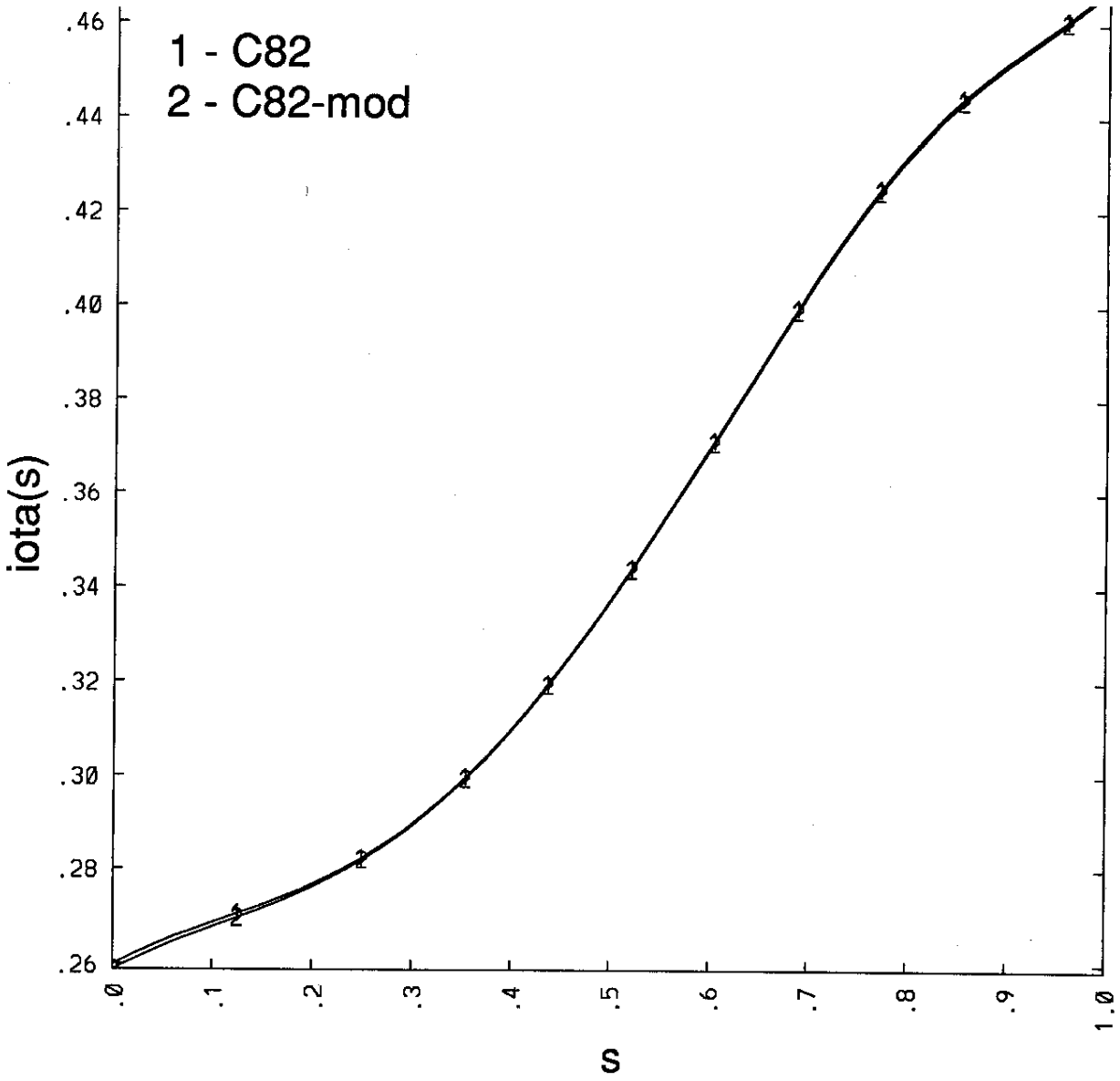




s=0.84




1 - C82
2 - C82-mod
ripple area
.09
.08
.07
.06
.05
.04
.03
.02
.01
.00
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
s


1 - C82
2 - C82-mod
iota(s)
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
s

- beginning with C82-mod, start to eliminate remaining R_{mn}, Z_{mn} one by one to see impact

(m,n)	Δ_{max} (from C82)	λ_K C82-mod $= -.4 \times 10^{-5}$	
(5,1)	4.9 mm	$-.73 \times 10^{-4}$	
(5,2)	6.9	$-.21 \times 10^{-3}$	*
(4,1)	7.9	$-.15 \times 10^{-3}$	*
(4,0)	5.0	$-.29 \times 10^{-4}$	
(3,3)	5.3	$-.66 \times 10^{-4}$	
(3,2)	23.7	$-.15 \times 10^{-2}$	*
(3,1)	15.0	$-.41 \times 10^{-3}$	
(3,0)	9.3	stable	
(3,-1)	7.2	$-.36 \times 10^{-4}$	

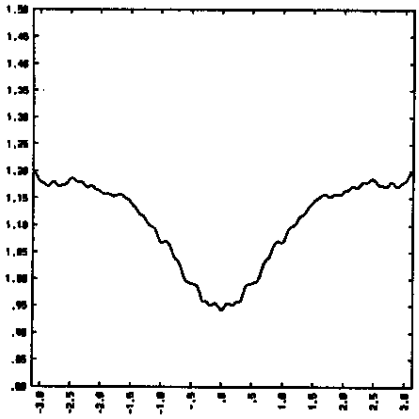
→ increasing magnitude of (5,2) or (4,1) by 40% stabilized kink

→ increasing magnitude of (3,2) by 50% stabilized kink

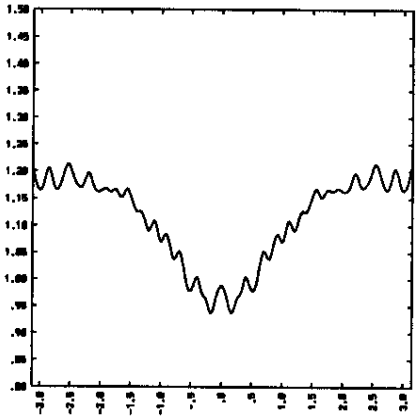
→ setting (5,1), (5,2), (4,1) and (4,0) to zero and increasing (3,2) magnitude to stabilize kink eliminates need for $m=5 \neq 4$ but worsens QA

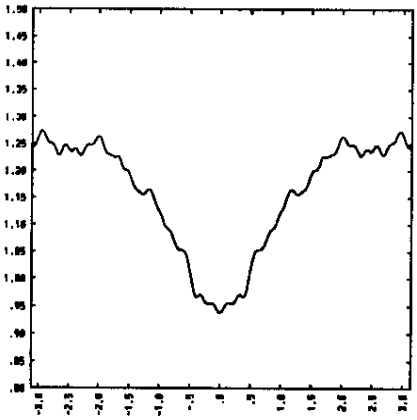
C82

C82-mod, m=5 and m=4 removed and R(m=3,n=2) increased to stabilize kink

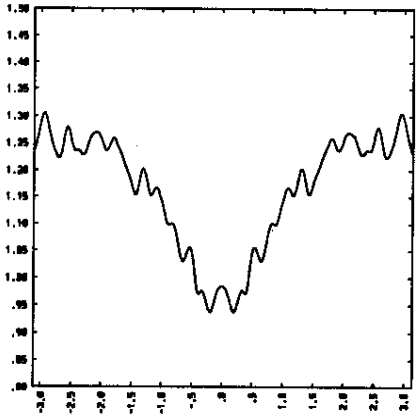


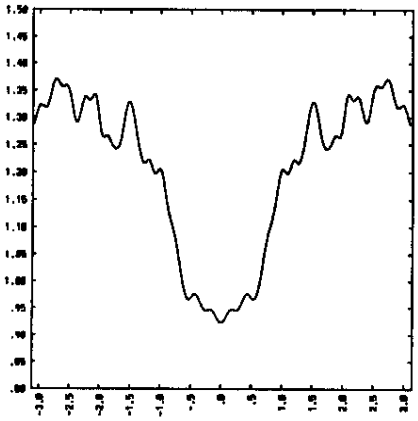
s = 0.34



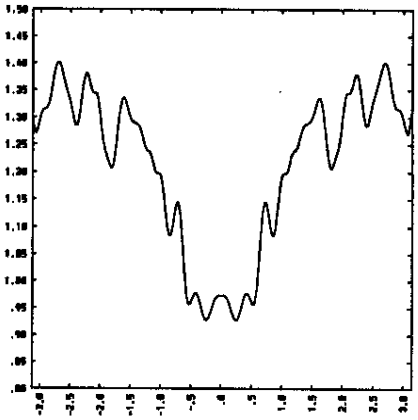


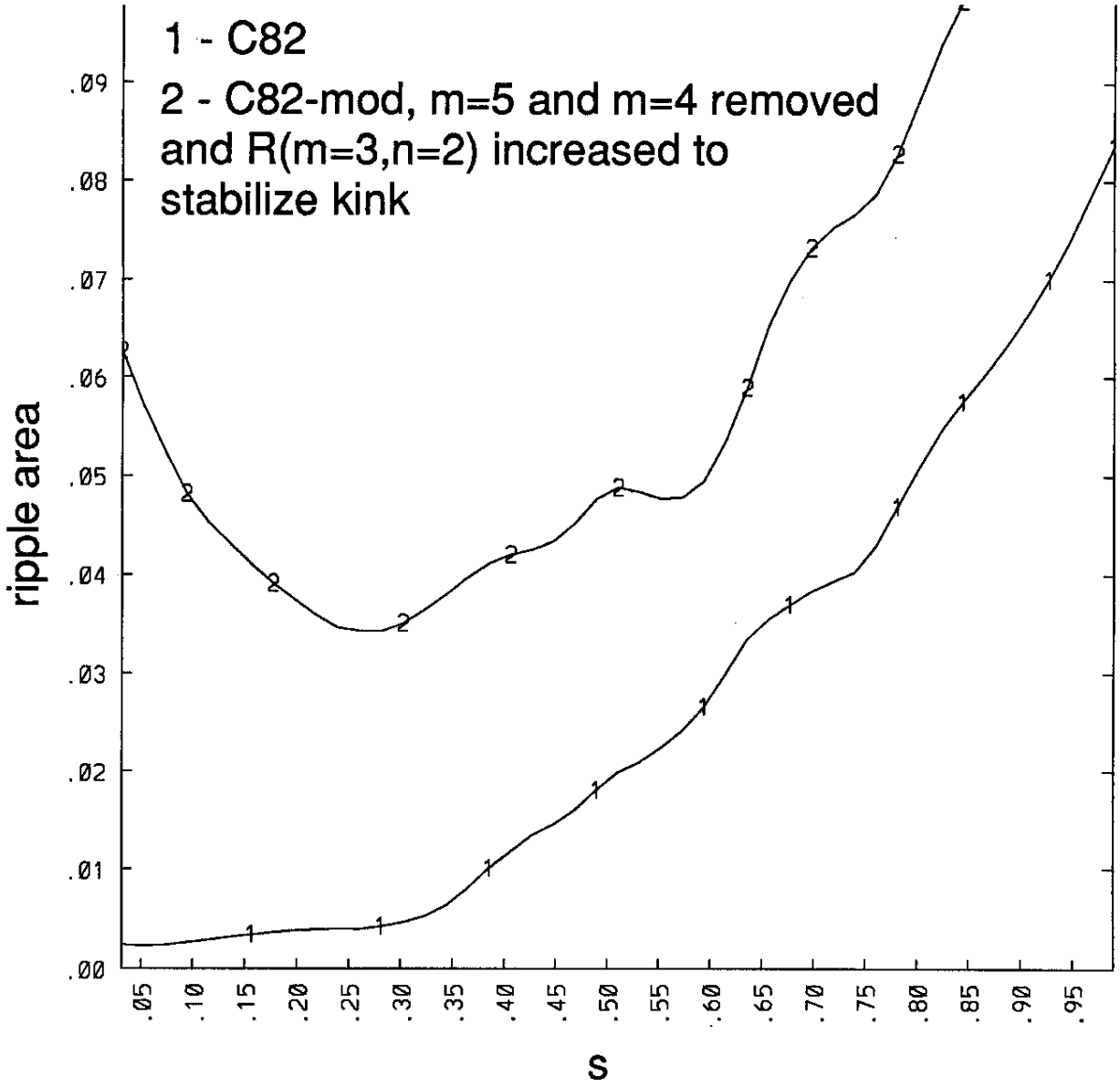
s = 0.55

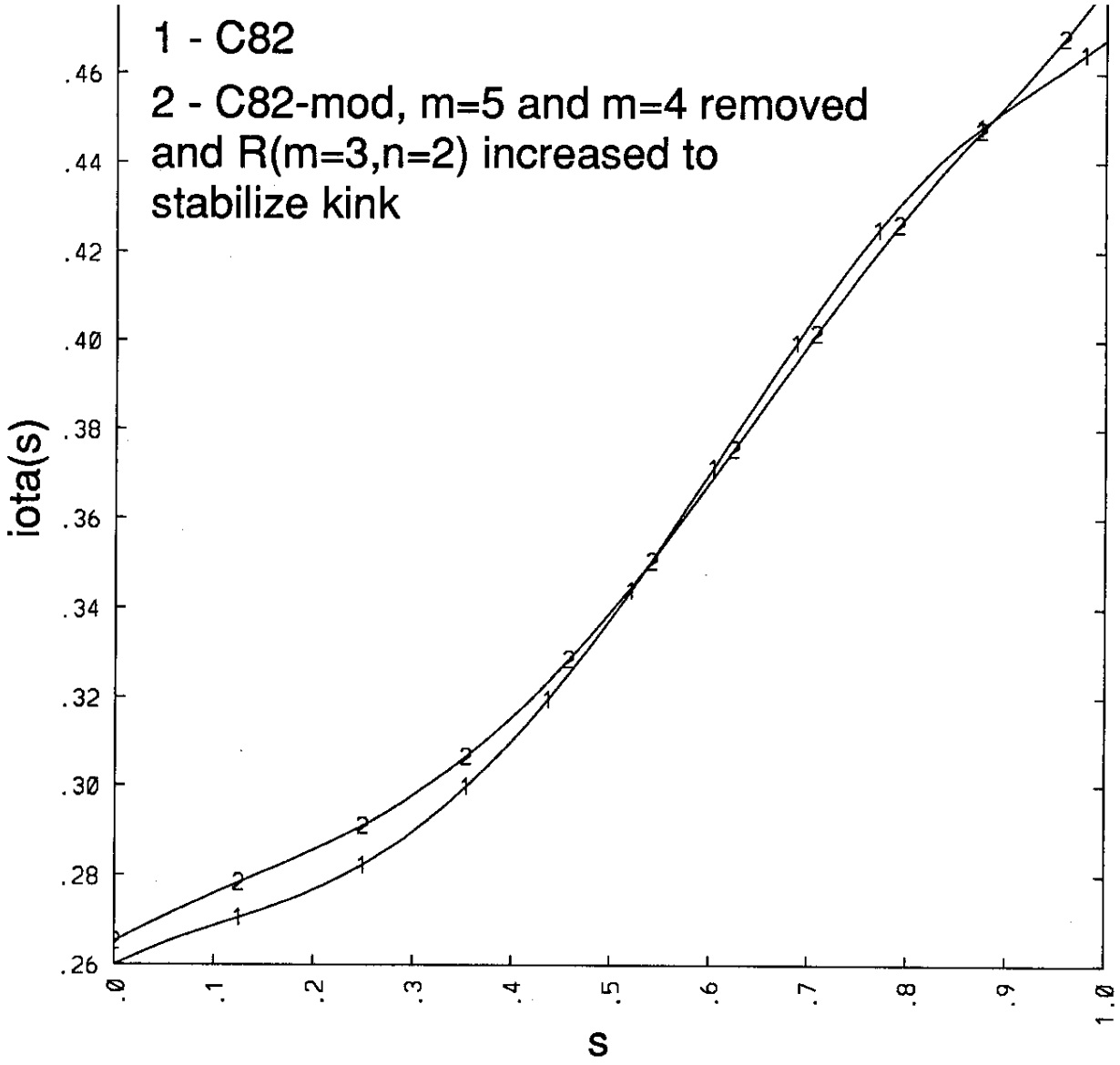




s = 0.84

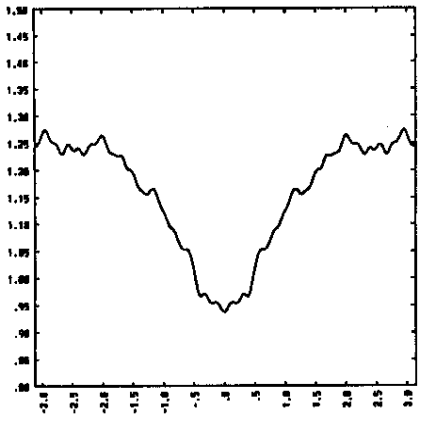


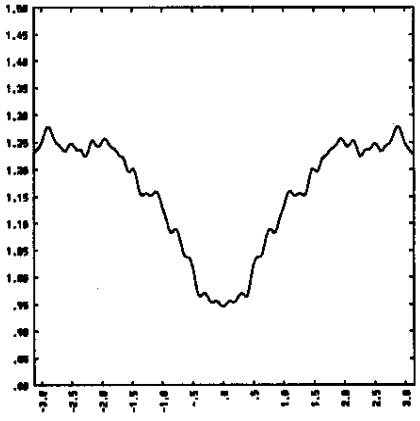

1 - C82
2 - C82-mod, m=5 and m=4 removed and R(m=3,n=2) increased to stabilize kink
ripple area
.00
.01
.02
.03
.04
.05
.06
.07
.08
.09
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
s


1 - C82
2 - C82-mod, m=5 and m=4 removed and R(m=3,n=2) increased to stabilize kink
iota(s)
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
s

C82

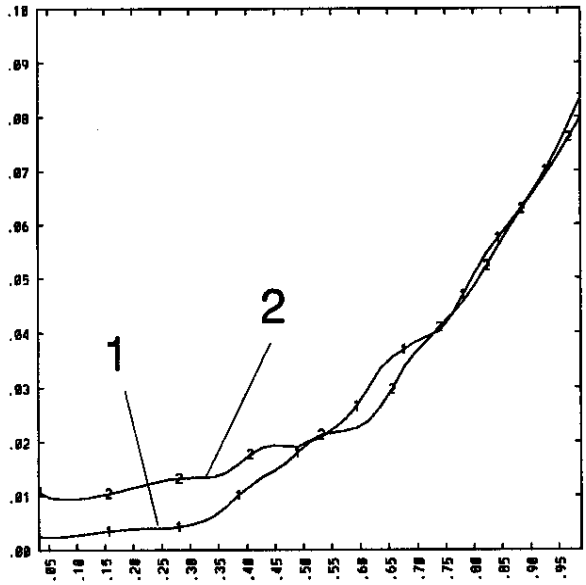
C82-mod, m=5 and m=4 removed

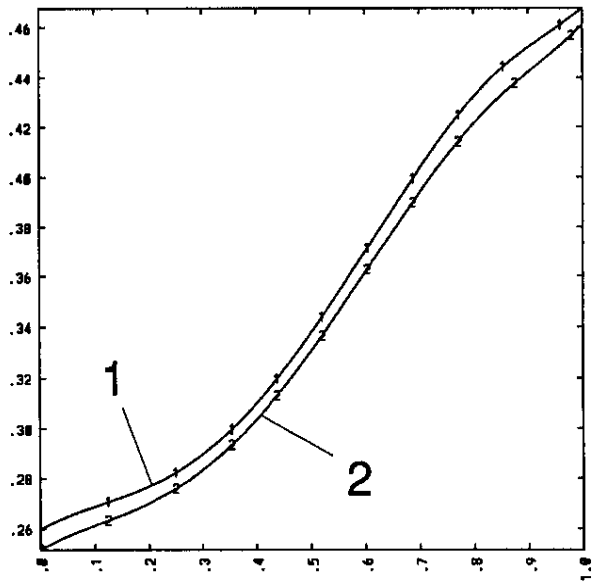




1 - C82

2 - C82-mod, m=5 and m=4 removed



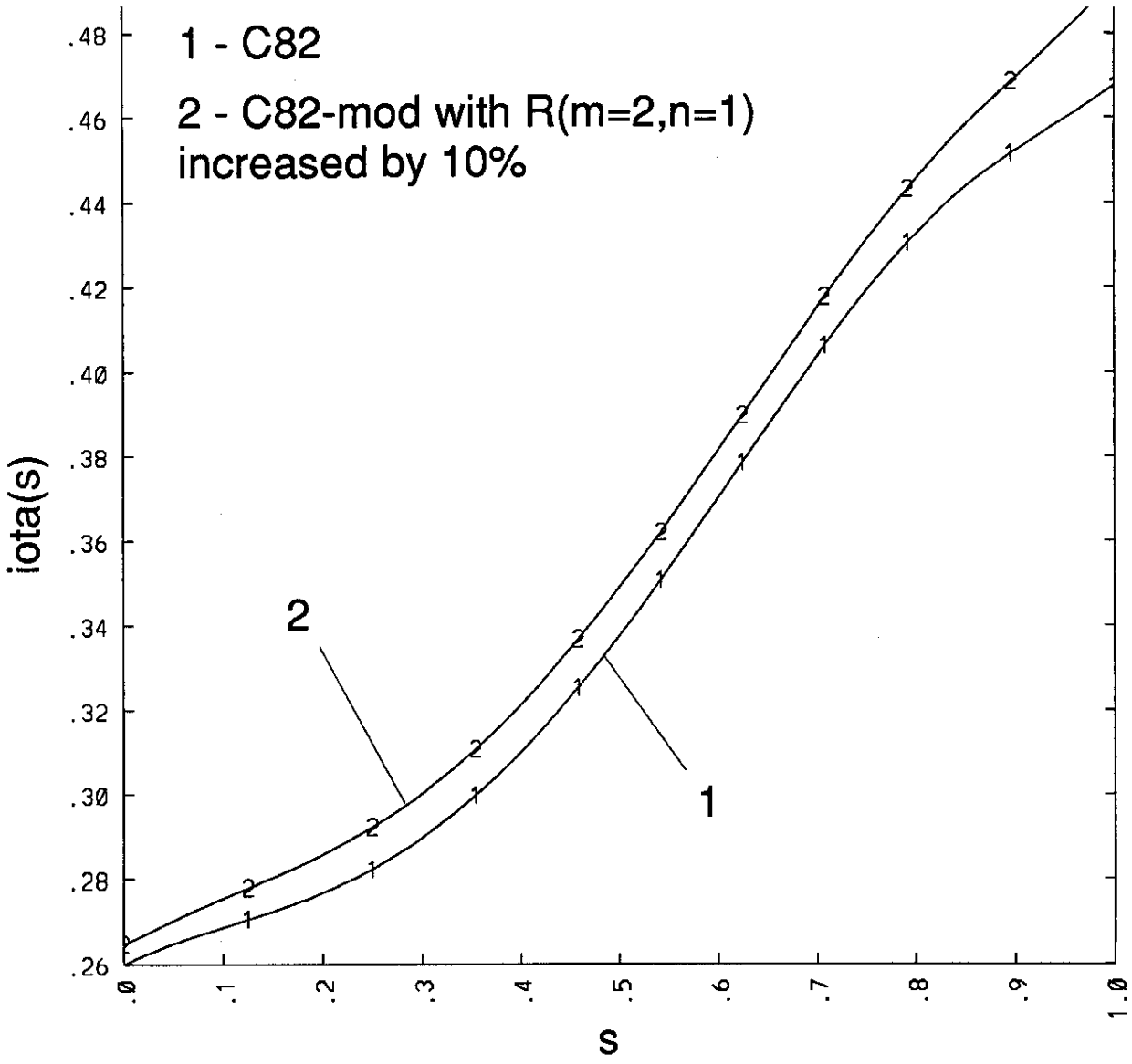


→ (3,2) shape term strongly affects $\iota(a)$ which is being constrained by optimizer to lie far enough away from $\iota = 0.5$

→ C82-mod with $m=5$ and $m=4$ removed has $\lambda_K = -.43 \times 10^{-3}$ and QA unaffected
$\Delta_{max} = 11.5$ mm

(m,n)	Δ_{max} (from C82)	C82-mod $\lambda_K = -.4 \times 10^{-5}$	
(2,2)	10.4 mm	stable	
(2,1)	126.0	$-.19 \times 10^{-2}$	*
(2,0)	71.4	$-.28 \times 10^{-3}$	
(2,-1)	54.2	$-.59 \times 10^{-3}$	
(2,-2)	2.1	$-.134 \times 10^{-5}$	
(2,-3)	1.6	$-.12 \times 10^{-4}$	

→ increasing R(2,1) magnitude by 10% reduced λ_K to $-.12 \times 10^{-5}$, and raised $\iota(a)$ to 0.489, strong impact on $\iota(s)$ overall

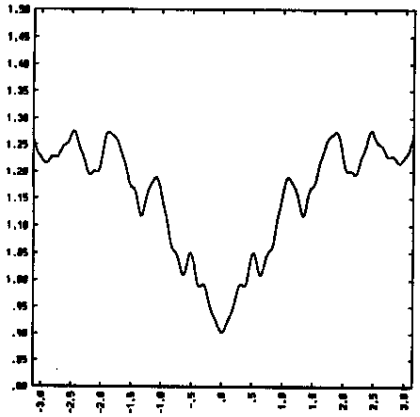

1 - C82
2 - C82-mod with R(m=2,n=1)
increased by 10%
iota(s)
s
.48
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2
1

(m,n)	Δ_{max} (from C82)	$\lambda_K^{C82\text{-}mod} = -.4\times10^{-5}$
(1,2)	20.1 mm	$-.21\times10^{-3}$
(1,1)	90.6	$-.19\times10^{-5}$ (stable)
(1,-1)	13.8	$-.17\times10^{-4}$
(1,-2)	12.1	$-.44\times10^{-6}$

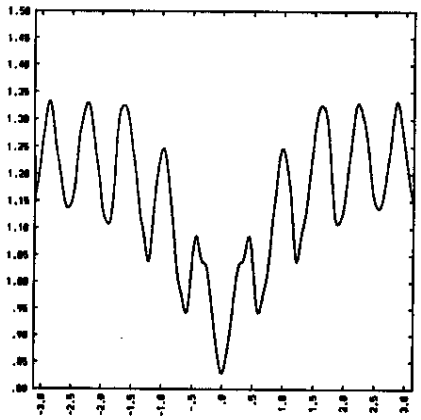
→ decreasing R(1,1) leads to stabilization of kink mode, this term contributes strongly to $\iota(s)$, and helps to keep plasma inside R_{min} / R_{max} boundaries, and contributes strongly to QA

(0,3)	3.2	$-.69\times10^{-5}$
(0,2)	9.8	$-.41\times10^{-4}$
(0,1)	78.0	stable

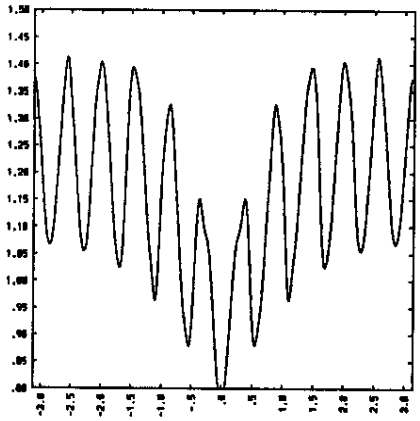
reducing R(1,1) shape term



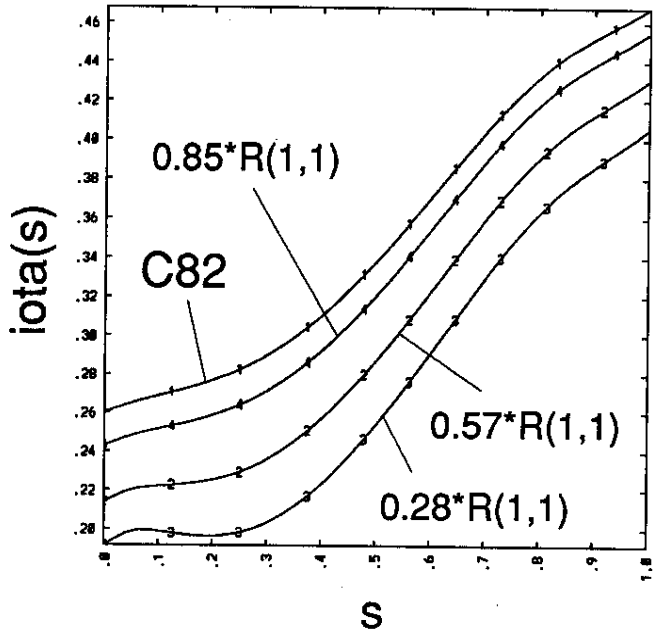
0.57*R(1,1)



0.28*R(1,1)



s = 0.55



- starting from C82-mod, remove shape terms that led to weak effect on kink and/or plasma boundary deformation

C82-mod-mod

(5,2)

(4,1)

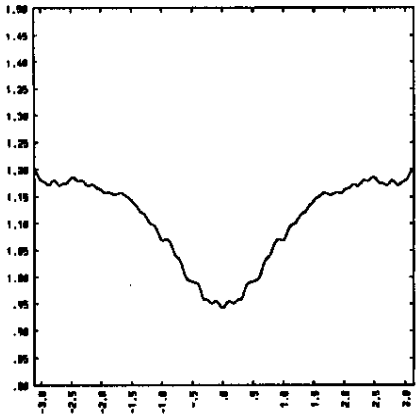
(3,2) ⟶ increase R(3,2) to obtain
(3,1) Kink stability (only by 25%)

(2,1)
(2,0)
(2,-1)

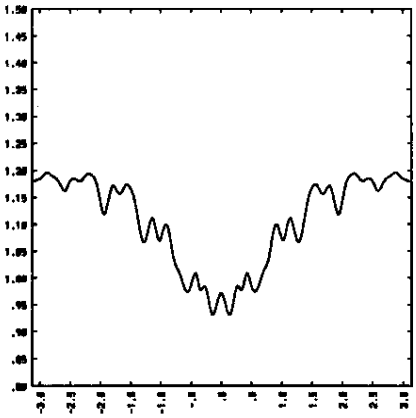
(1,2)
(1,1)
(1,0)
(1,-1)
(1,-2)

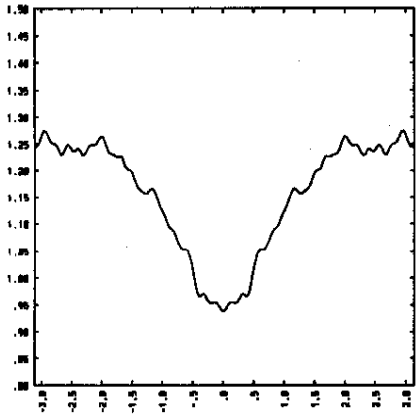
(0,1)
(0,0)

⟶ if remove (5,2) & (4,1) & increase R(3,2) further can stabilize kink and QA appears slighty worse than C82-mod-mod

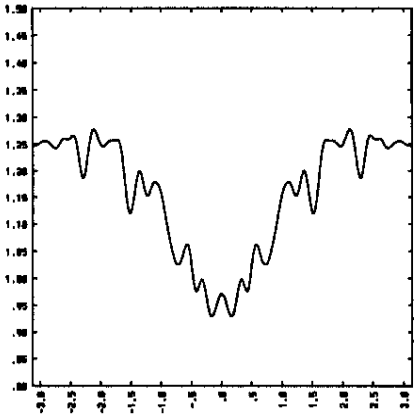


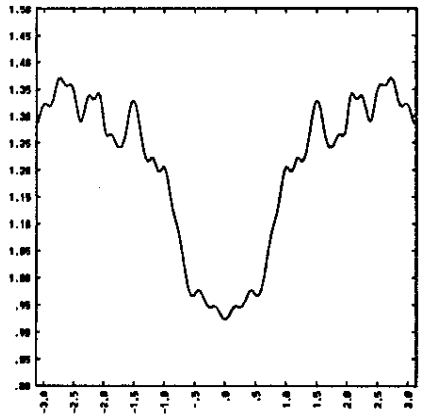
s = 0.34



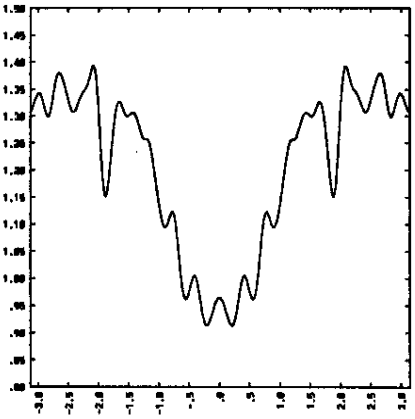


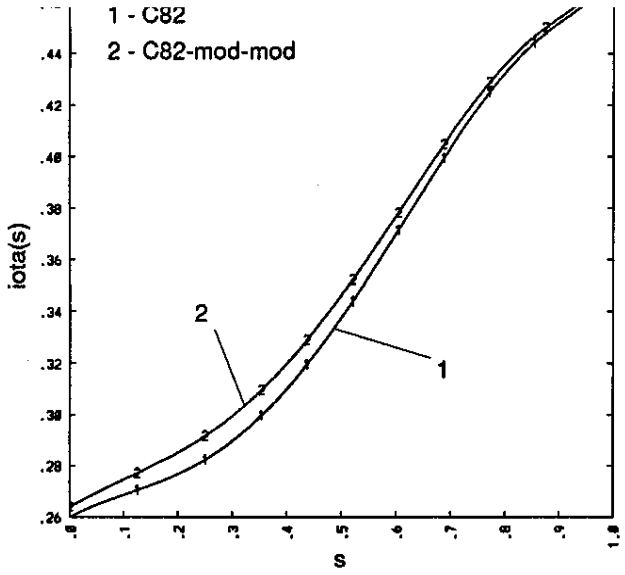
s = 0.55

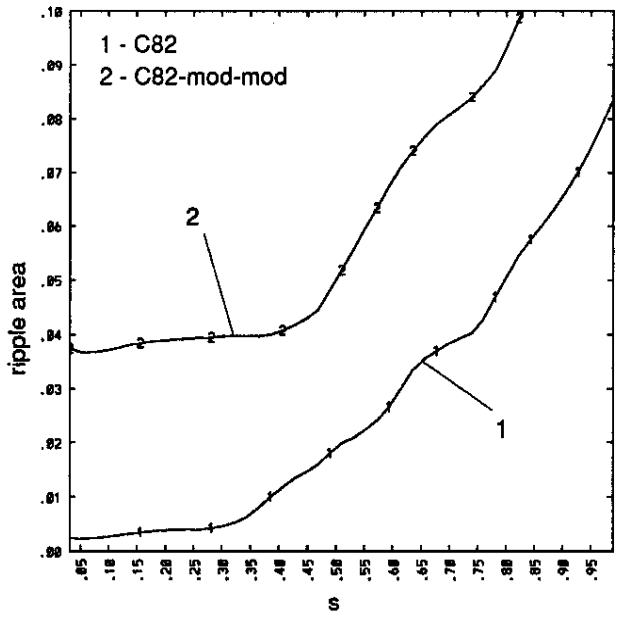




s = 0.84

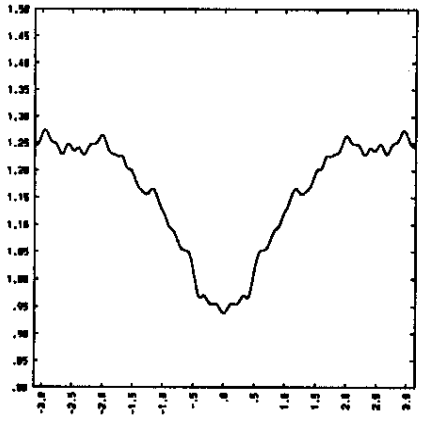


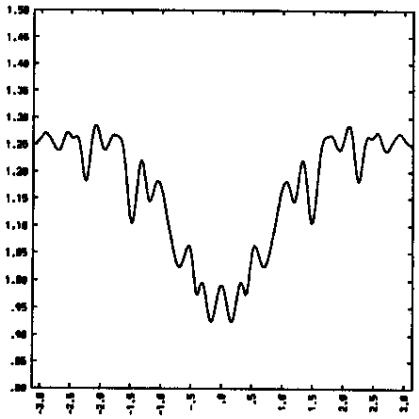

1 - C82
2 - C82-mod-mod
iota(s)
s
2
1


1 - C82
2 - C82-mod-mod
ripple area
s
2
1

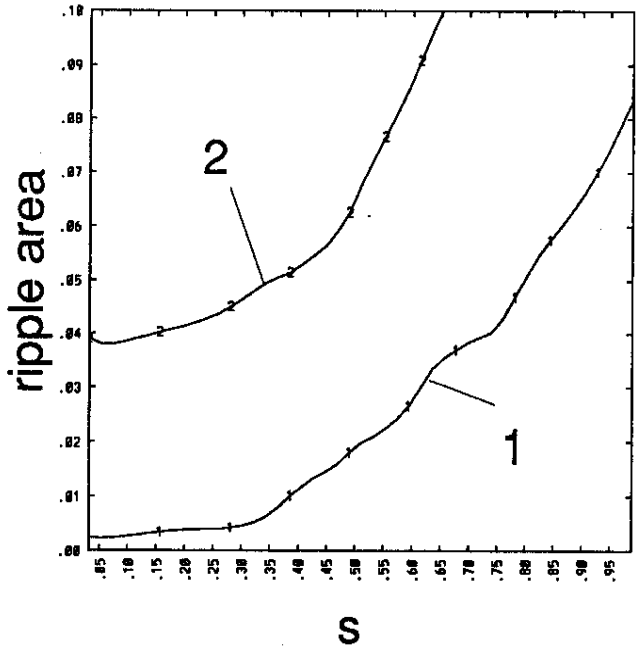
C82

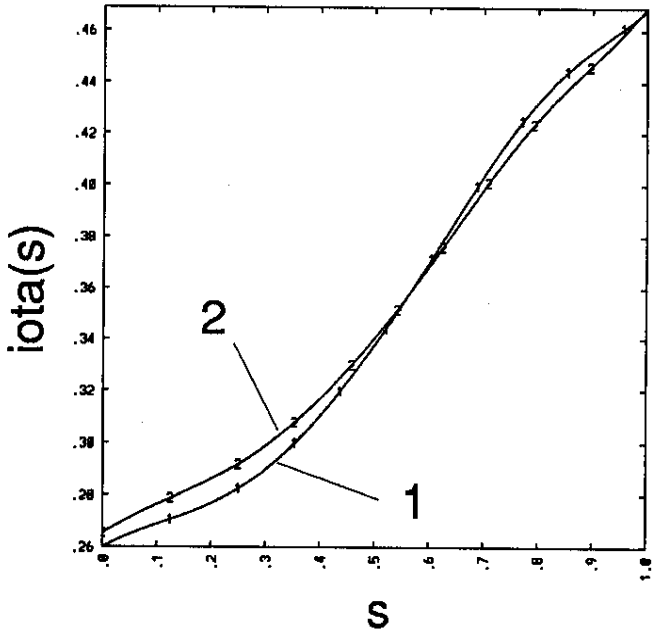
C82-mod-mod, with (5,2) and (4,1) removed





1 - C82
2 - C82-mod-mod, with (5,2) and (4,1) removed





Comments

- we can remove several shape terms from C82 without significant impact on
  - plasma boundary
  - kink stability
  - QA (?)

- certain terms have strong impact on kink stability
  - (5,2), (4,1), (3,2), (2,1)

- some shape terms strongly impact $\iota(a)$ and possibly also $\iota(s)$
  - (3,2), (2,1), (1,1)

- so far only (1,1) term showed strong impact on QA, although non-dominant shape terms seem to contribute to QA collectively

- from the experimental point of view should we rely on lower (m,n) shape terms that contribute stronly to Δ, λ_K & $\iota(s)$

  or rely on high (m,n) terms, that for example help stabilize the kink but have little impact on Δ or $\iota(s)$