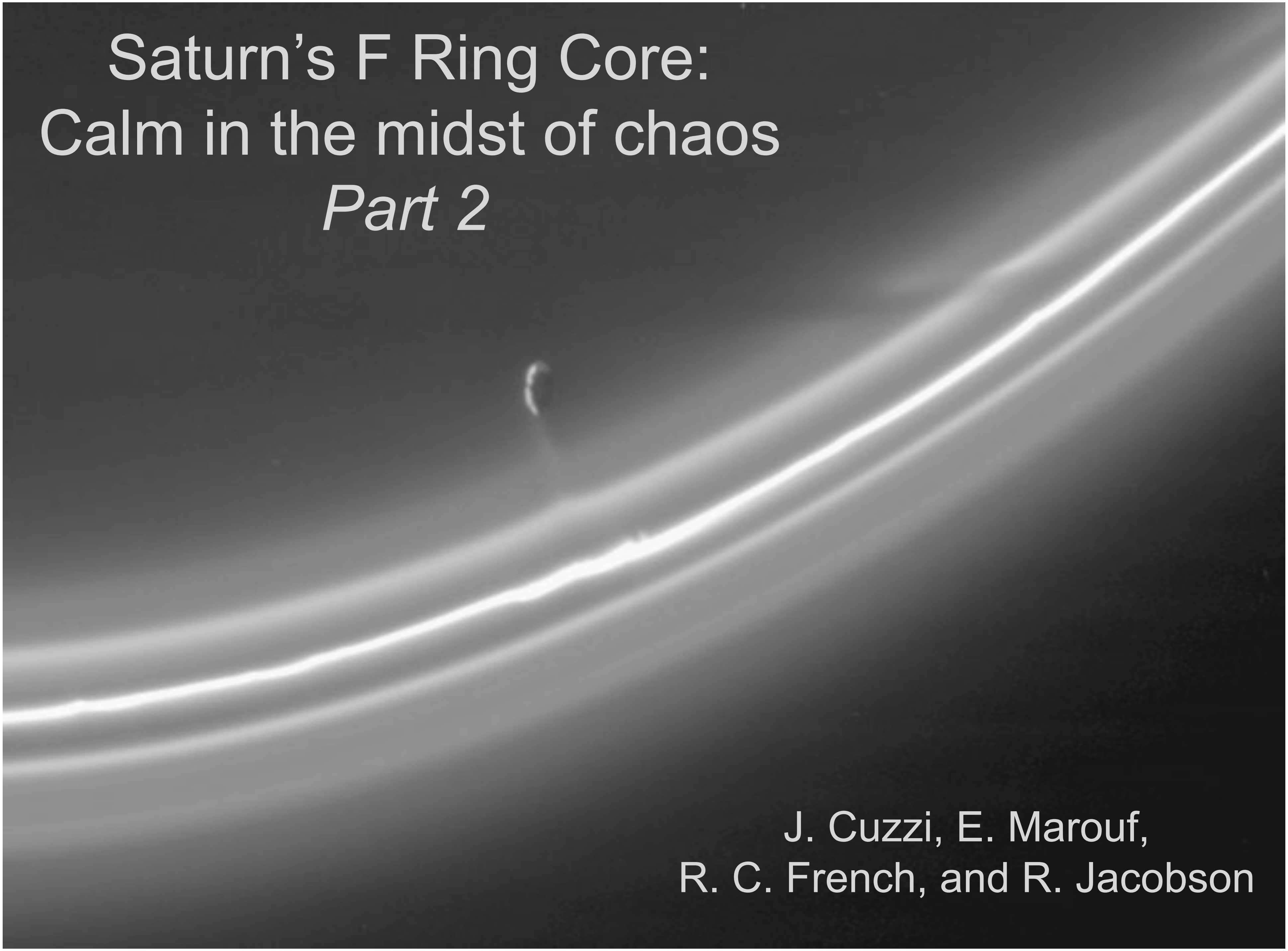
Saturn's F Ring Core:
Calm in the midst of chaos
Part 2
J. Cuzzi, E. Marouf,
R. C. French, and R. Jacobson

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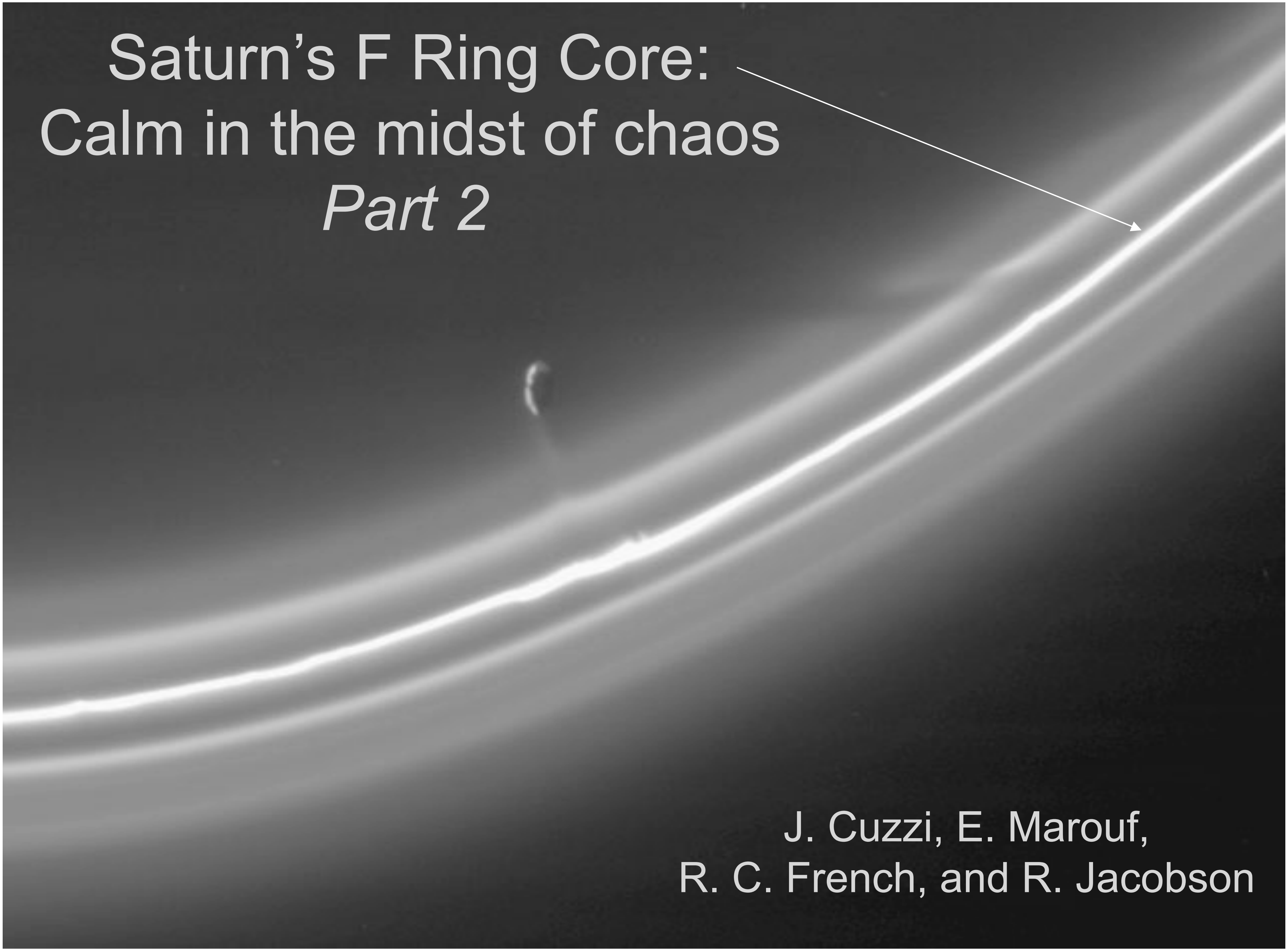

J. Cuzzi, E. Marouf,
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The F ring core is very narrow

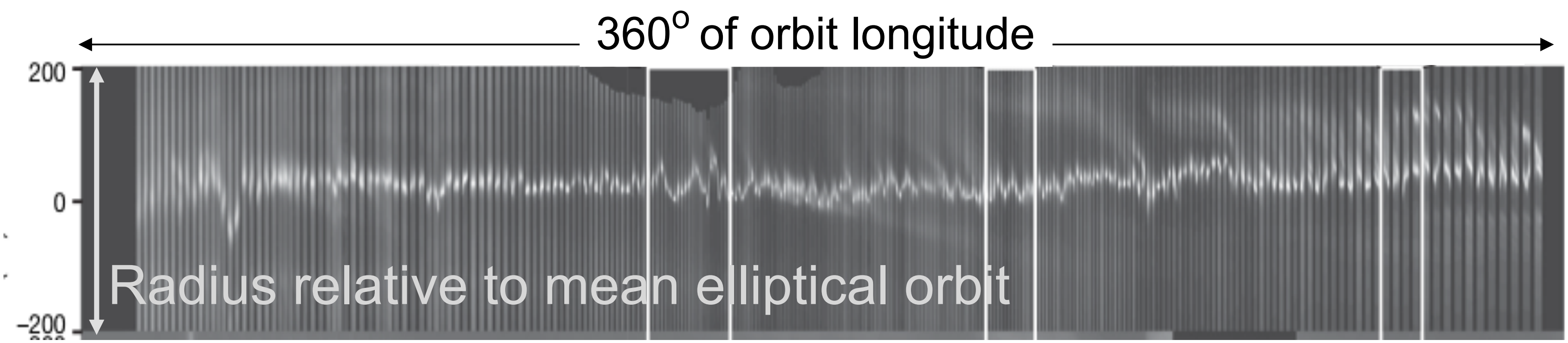
(<1km from occultations; Marouf et al 1986; 2011a,b),

It contains numerous sizeable embedded objects

(Murray et al 2008, Esposito et al 2008, Beurle et al 2010),

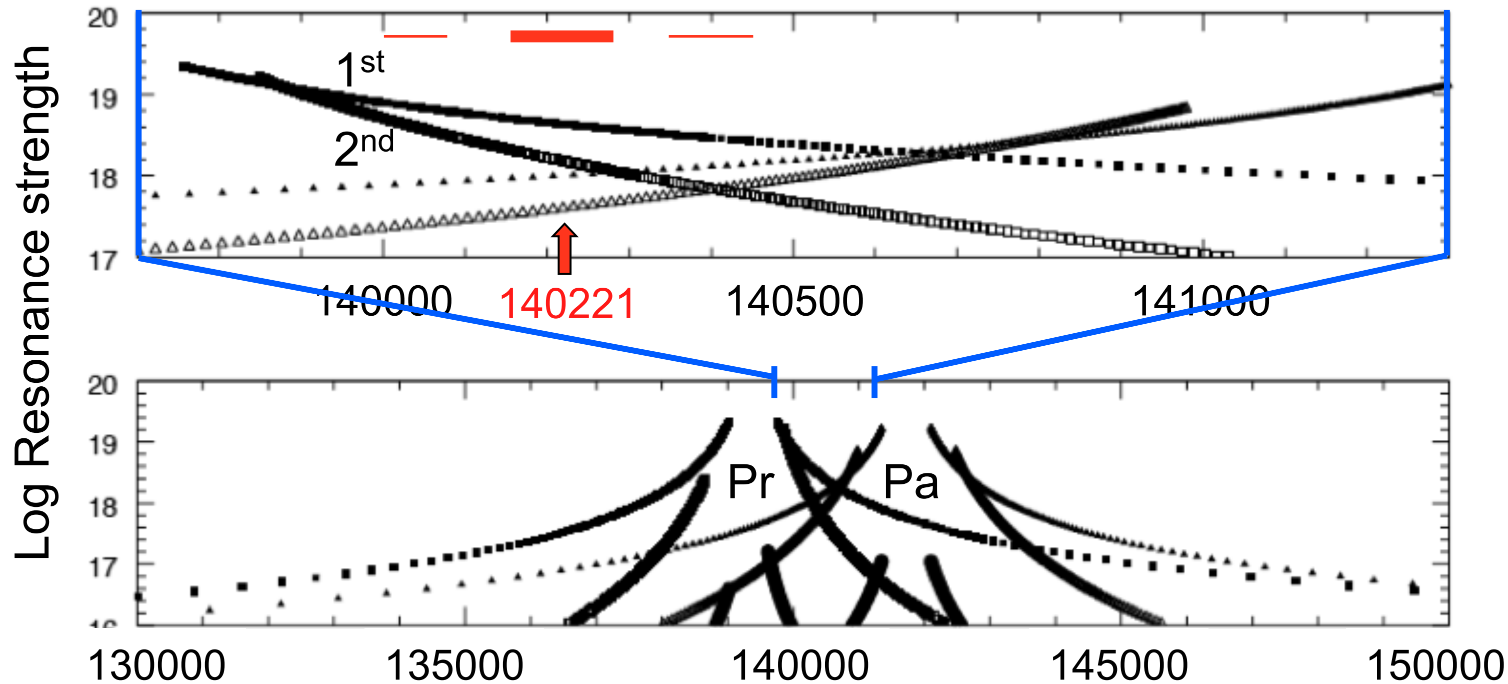
and it has maintained a very stable orbit over decades

(Bosh+2002, Marouf+2011a,b, Albers+2012, Cooper+2012).

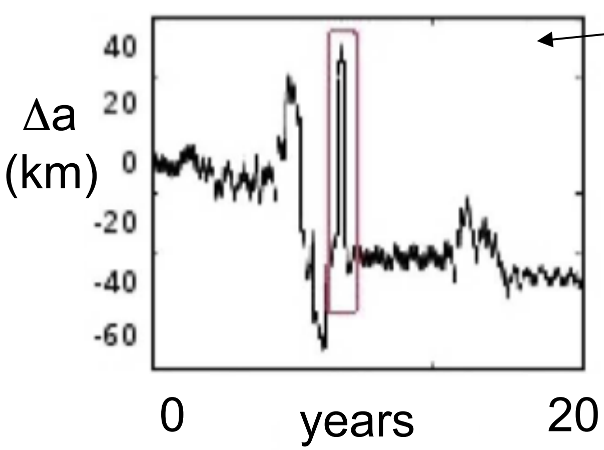


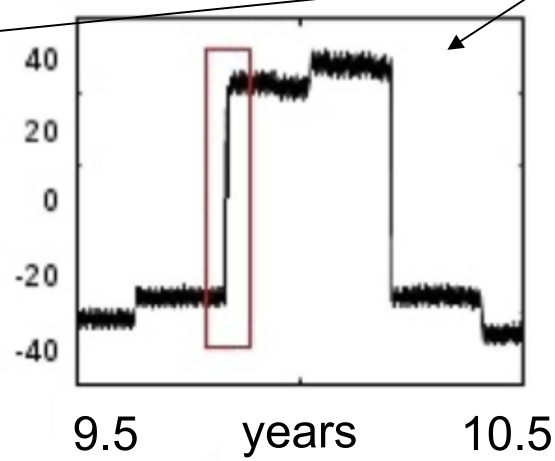
How can this be, in the face of pervasive orbital chaos??

F Ring region is filled by closely spaced resonances



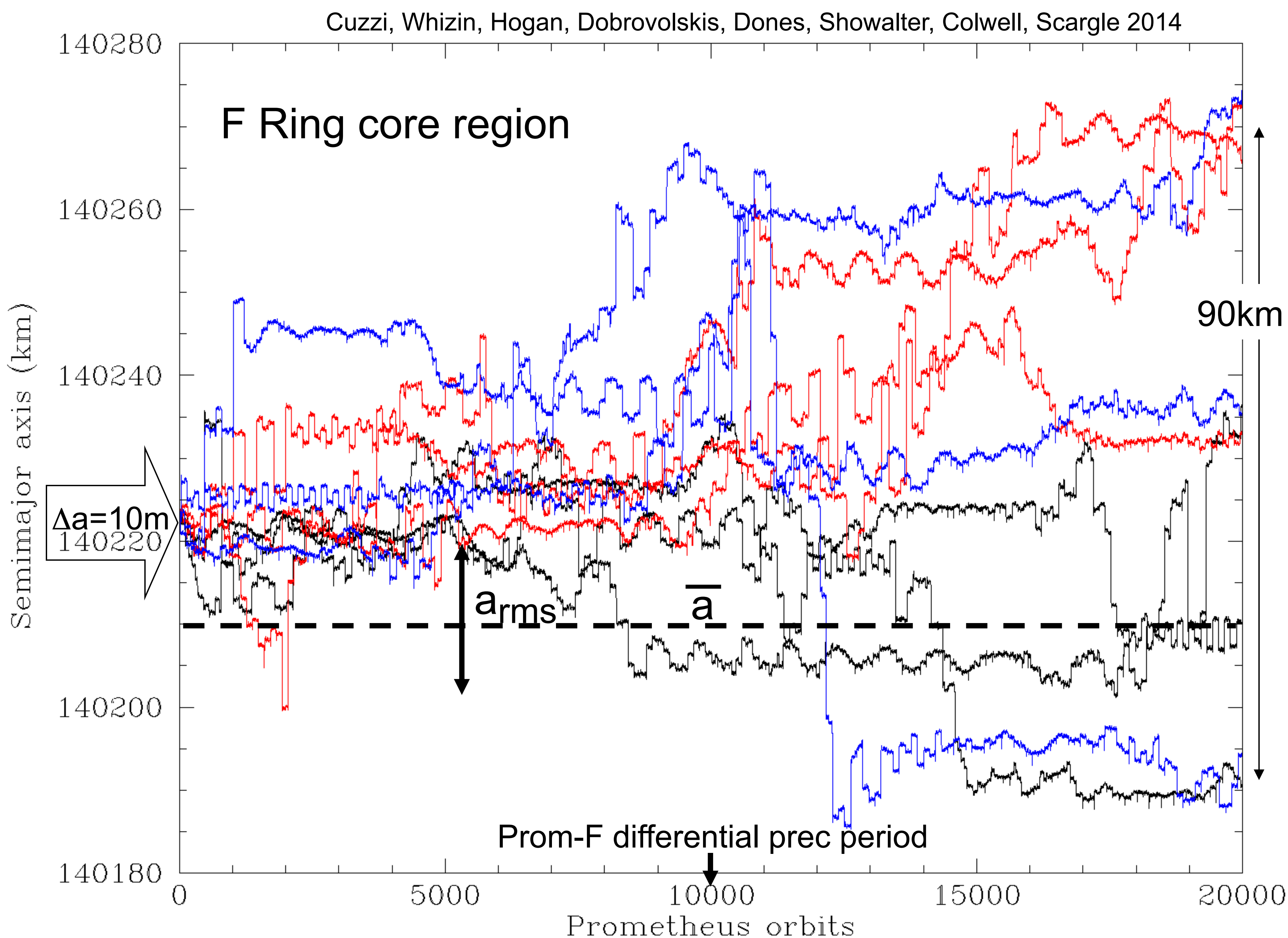
Orbital chaos is pervasive (Scargle et al 1993, Winter et al 2007, 2010)

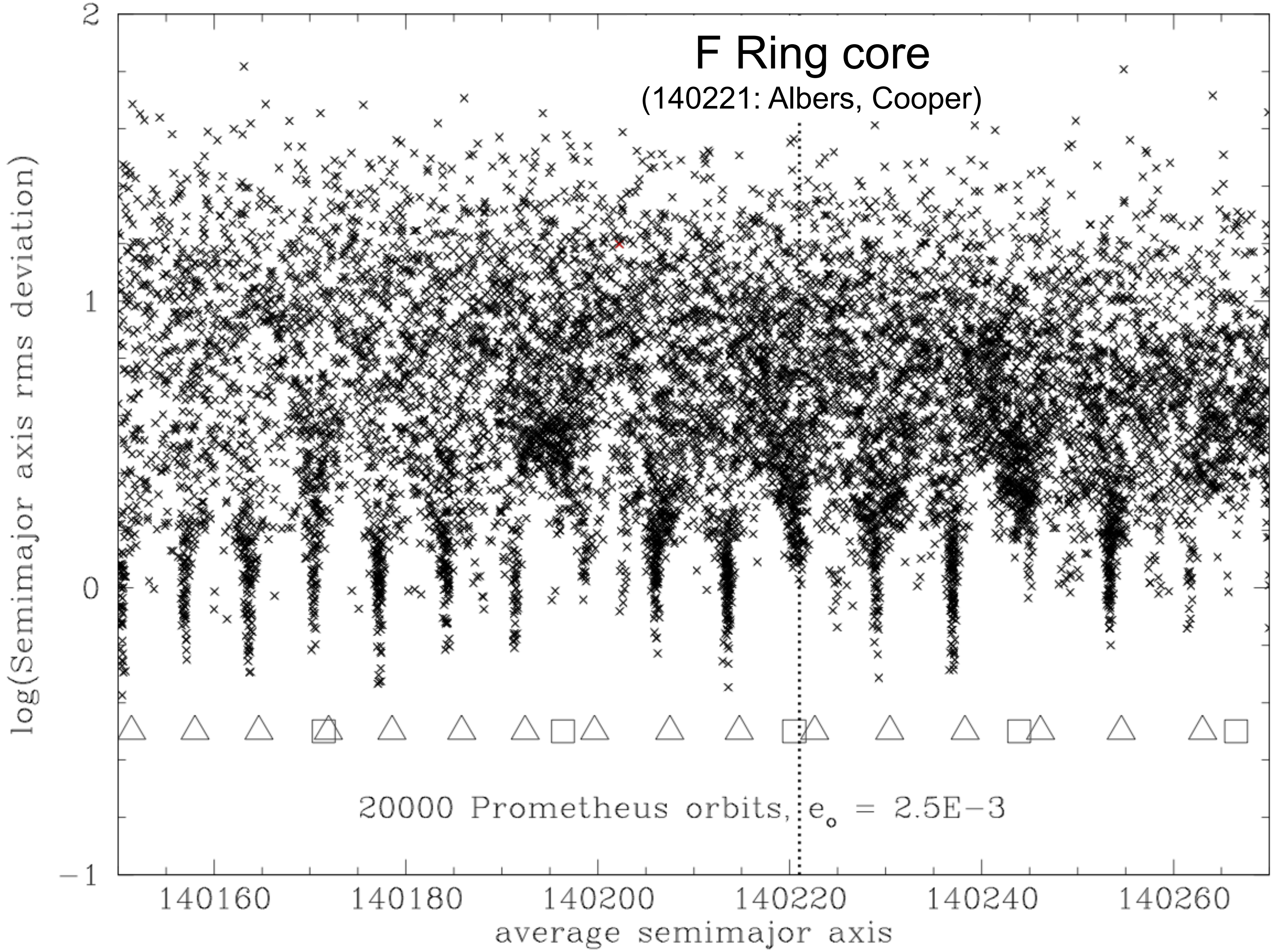




"…all particles in core region are chaotic"; most extreme case shown.

ISS continues to have trouble tracking objects (Cooper et al 2006)

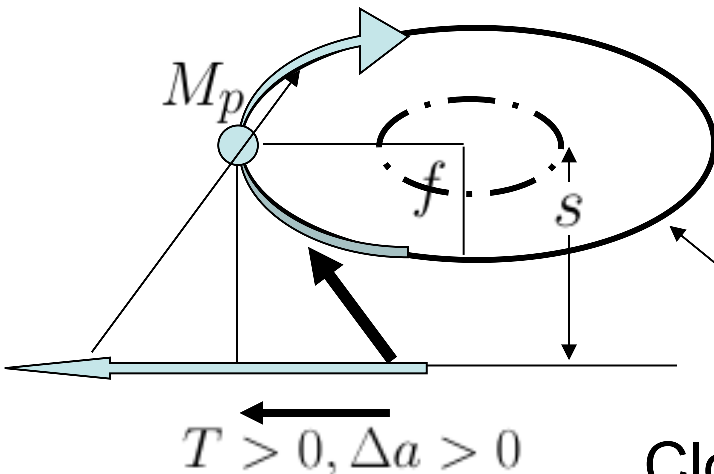

Cuzzi, Whizin, Hogan, Dobrovolskis, Dones, Showalter, Colwell, Scargle 2014
F Ring core region
90km
Δa=10m
a_{rms}
$\overline{a}$
Prom-F differential prec period
Semimajor axis (km)
Prometheus orbits
140280
140260
140240
140220
140200
140180
0
5000
10000
15000
20000

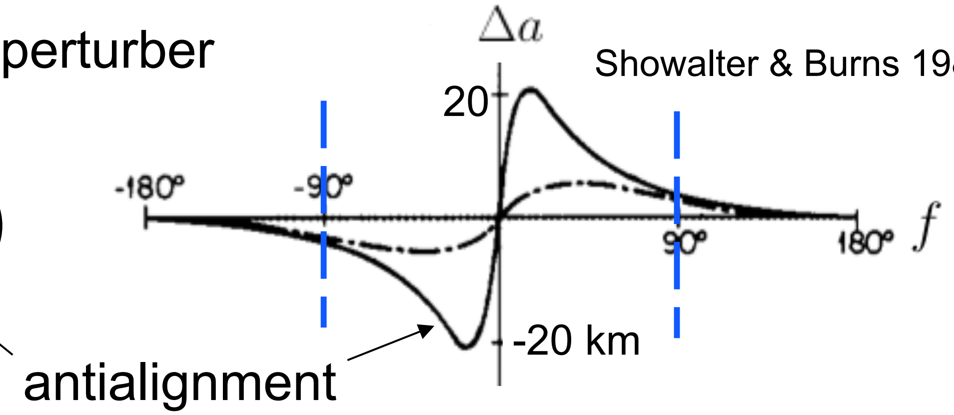


Cuzzi et al 2014

Perturbation by Prometheus impulses

Merge (e, ϖ) of particle and perturber





$$T \sim \frac{GM_p}{s^2}\frac{ae}{2s}\sin f \gg eR$$

Δa ~ few km

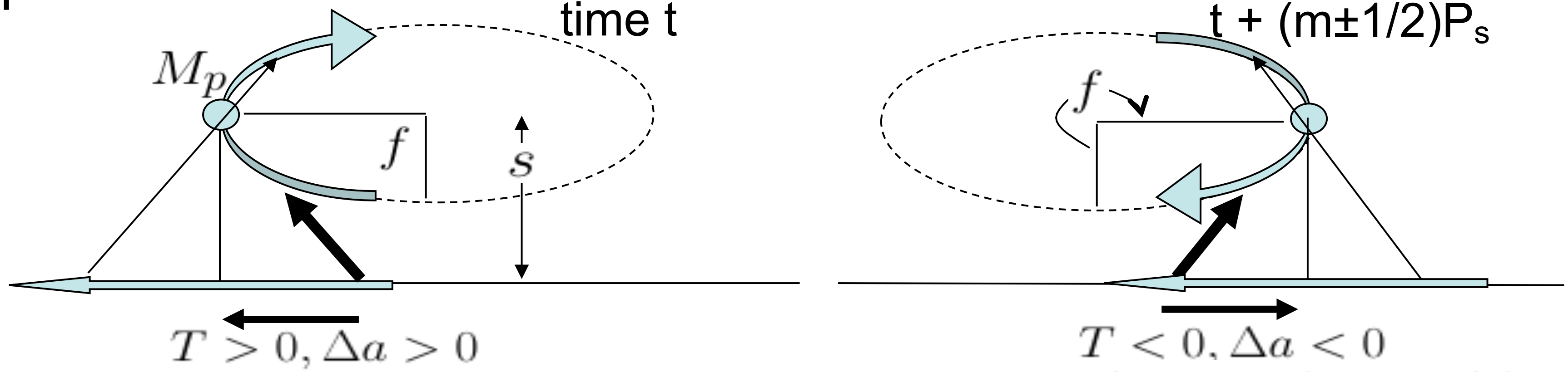
Close/eccentric encounters change semimajor axis and synodic period.

Subsequent encounters generally lead to chaotic diffusion of a -

unless canceled immediately, on next encounter after P_{syn}. We call orbits where this occurs "antiresonances".

Cuzzi et al 2014

Simple case



If $\dot{\varpi} = 0$, cancellation at antiresonance when $\Omega_s/\Omega_{syn} = (m \pm 1/2)$

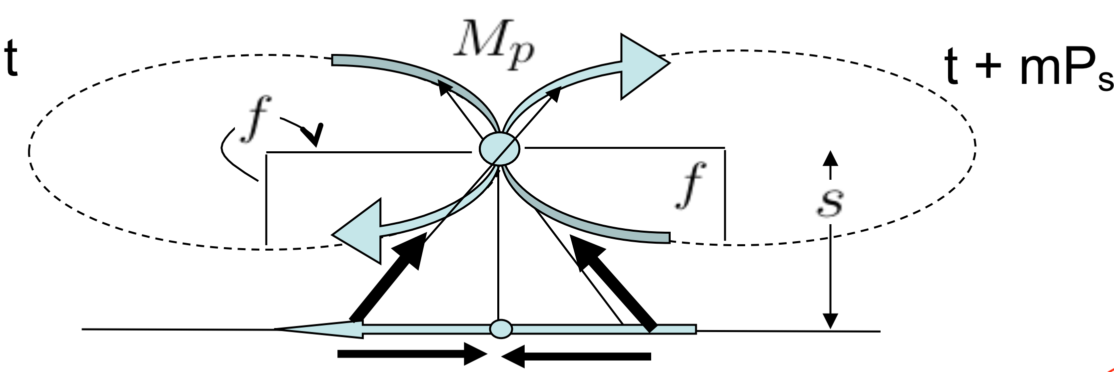
Stable locations are halfway between resonances

Simple case

If $\dot{\varpi} = 0$, cancellation at antiresonance when $\Omega_s/\Omega_{syn} = (m \pm 1/2)$

Stable locations are halfway between resonances

Actual case



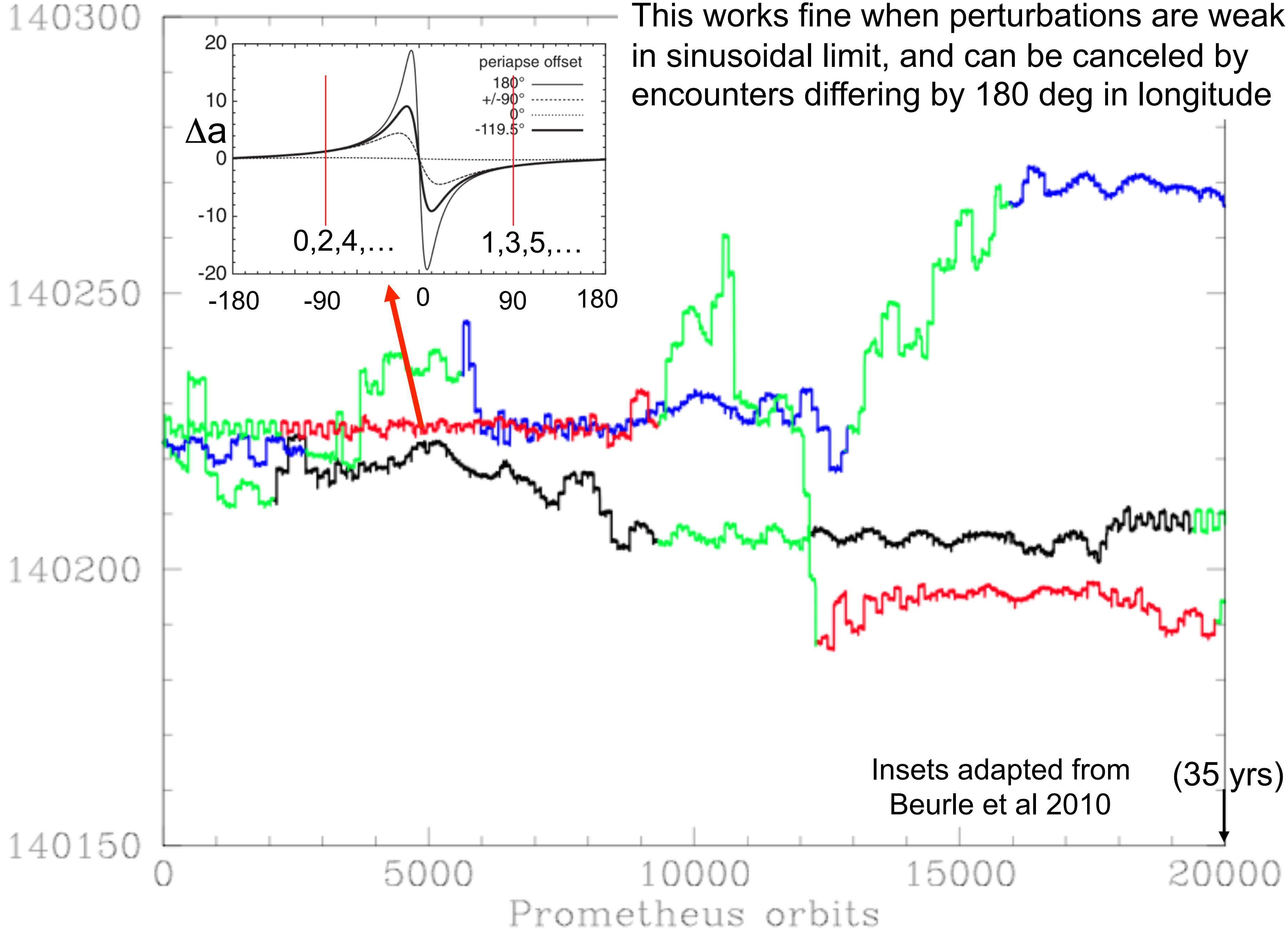
Now we obtain cancellation when $m \pm \frac{1}{2} = \frac{\kappa_s}{\Omega_{syn}} = \frac{\Omega_s}{\Omega_{syn}} - \frac{\dot{\varpi}}{\Omega_{syn}}$

And because $\frac{\dot{\varpi}}{\Omega_{syn}} \sim 1/2$, get "antiresonances" where $\Omega_s/\Omega_{syn} = m$

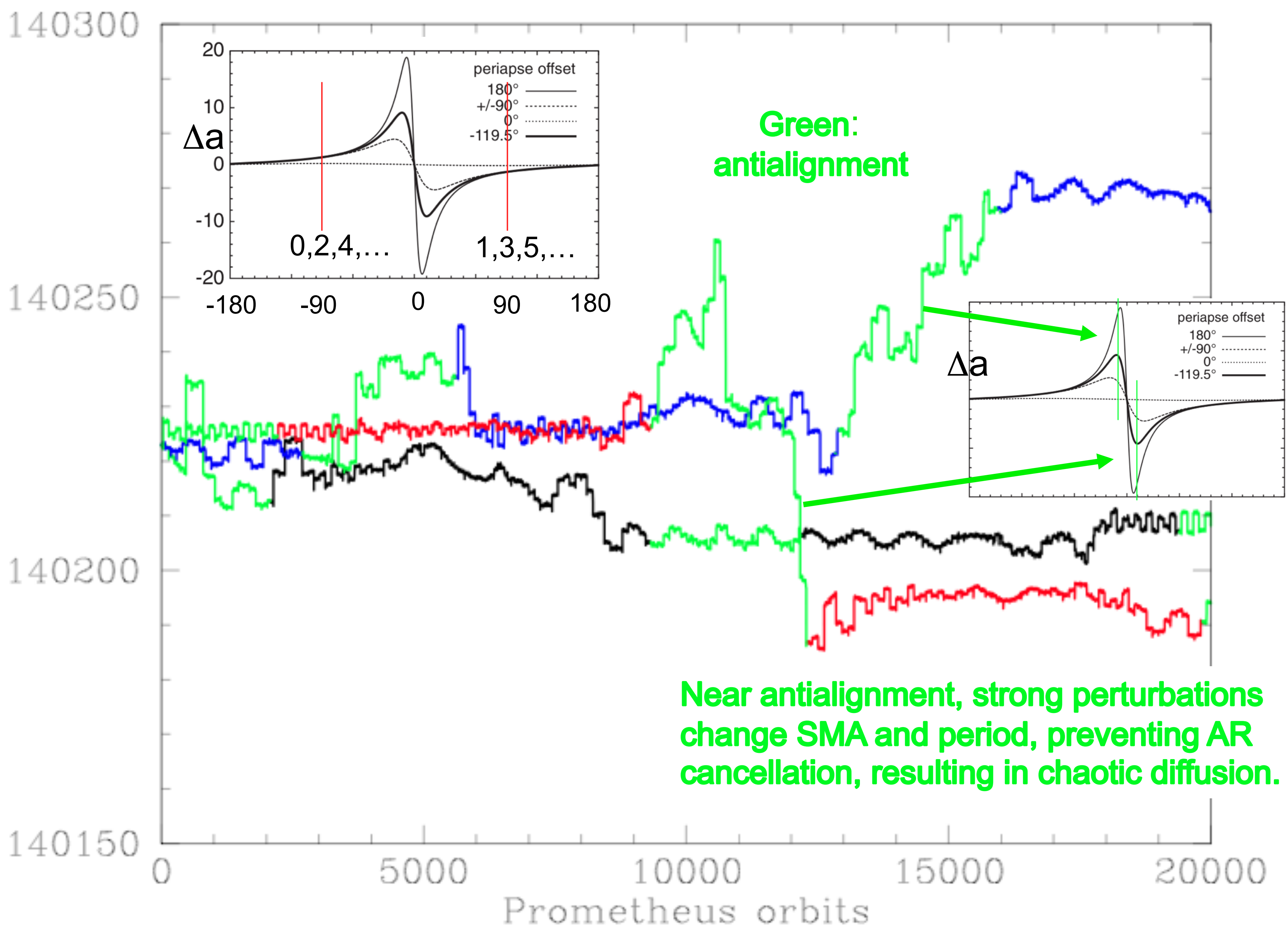
That is, at or near resonances, not halfway between them

Cuzzi et al 2014

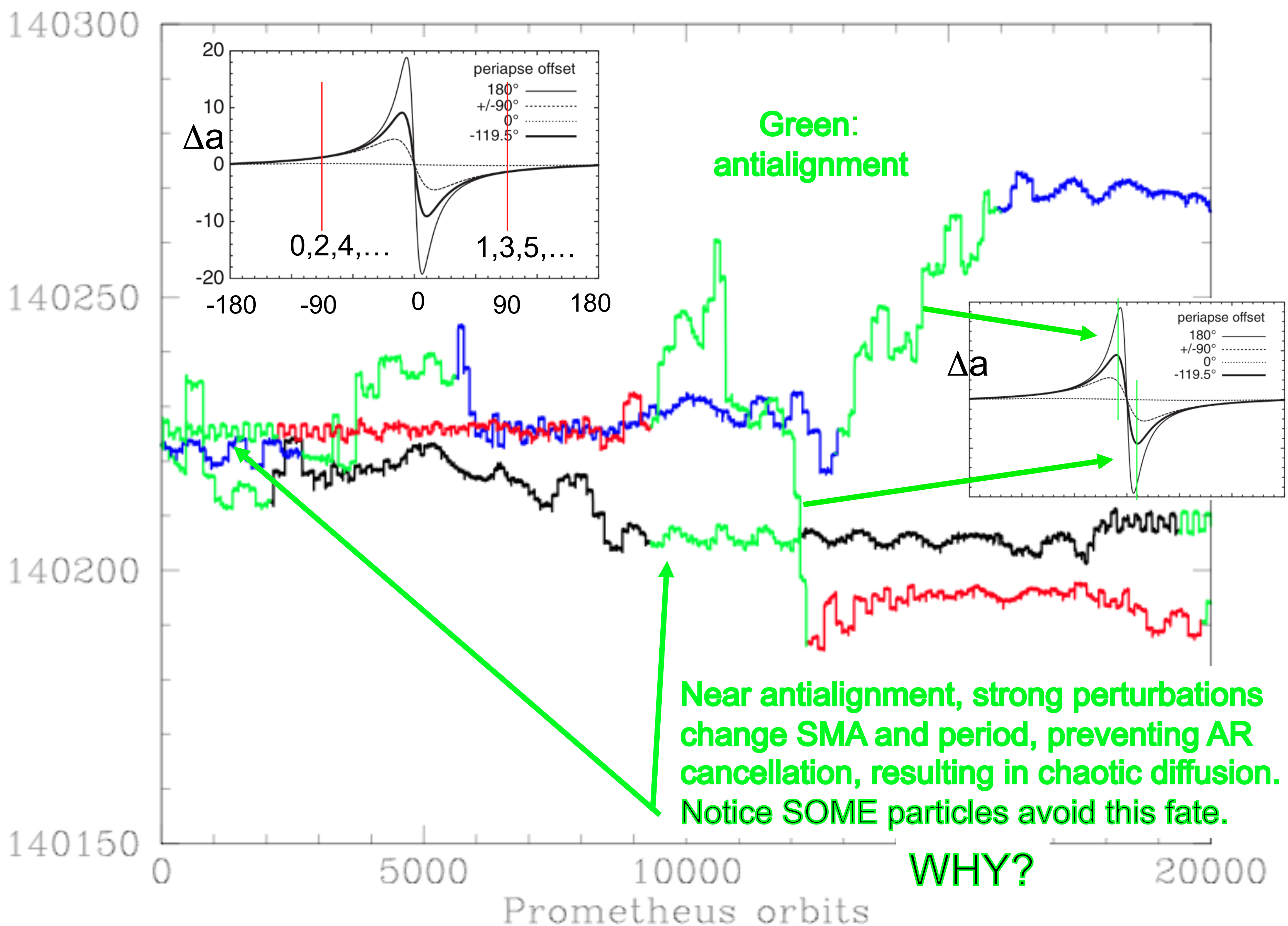
This works fine when perturbations are weak, in sinusoidal limit, and can be canceled by encounters differing by 180 deg in longitude



Insets adapted from Beurle et al 2010

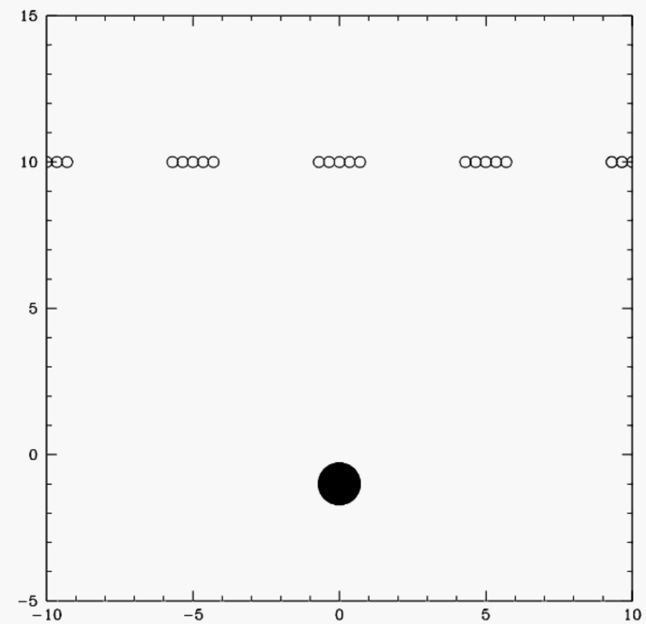


140300
140250
140200
140150
0
5000
10000
15000
20000
Prometheus orbits
Δa
periapse offset
180°
+/-90°
0°
-119.5°
20
10
0
-10
-20
-180
-90
0
90
180
0,2,4,…
1,3,5,…
Green:
antialignment
Near antialignment, strong perturbations change SMA and period, preventing AR cancellation, resulting in chaotic diffusion.



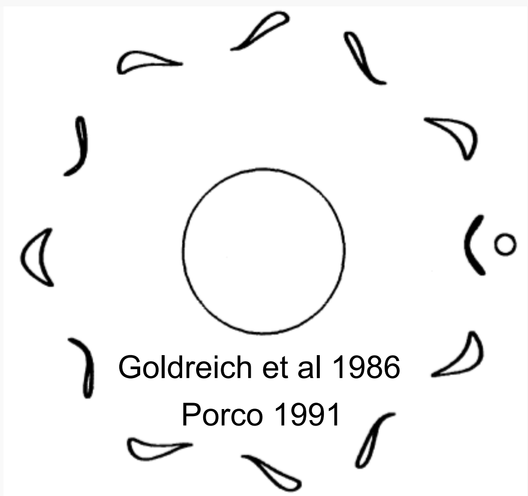
Green: antialignment
Near antialignment, strong perturbations change SMA and period, preventing AR cancellation, resulting in chaotic diffusion.
Notice SOME particles avoid this fate.
WHY?
Prometheus orbits
periapse offset
180°
+/-90°
0°
-119.5°
Δa
0,2,4,…
1,3,5,…
140300
140250
140200
140150
0
5000
10000
20000

To preserve the long-term stability *possible* at AR's, particles can *never encounter Prometheus when it is near its apoapse*...........

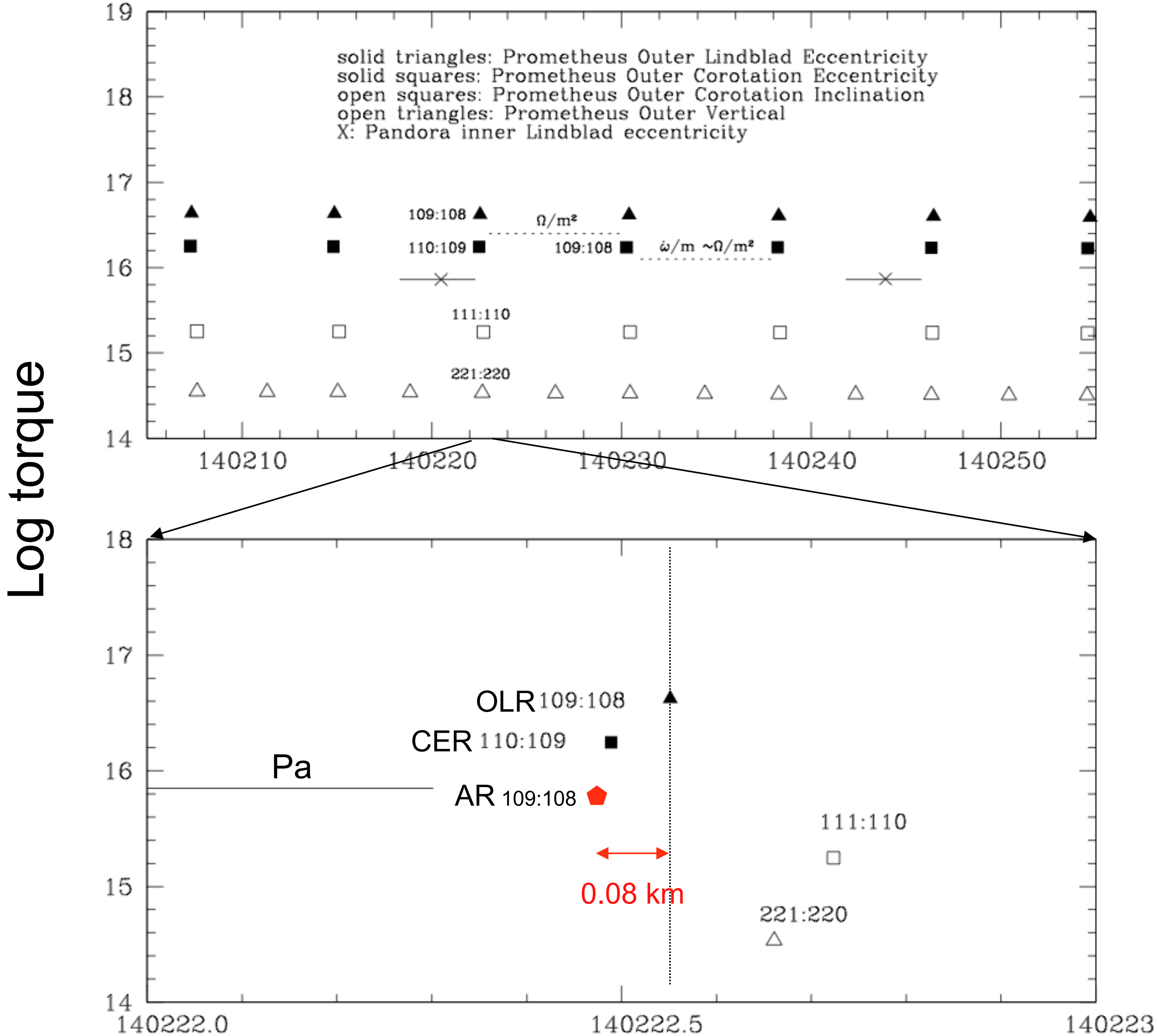


Suggests that *corotational resonance* acts to select/maintain long-term stable *longitudes* wrt Prometheus.

Neptune's arcs are confined by torques in a *2m*-fold CIR (inclination type; *m*=86, due to the very low eccentricity of Galatea), with energy input from the Galatea *m*=43 ILR. For Prometheus, the CER (eccentricity type) dominates.



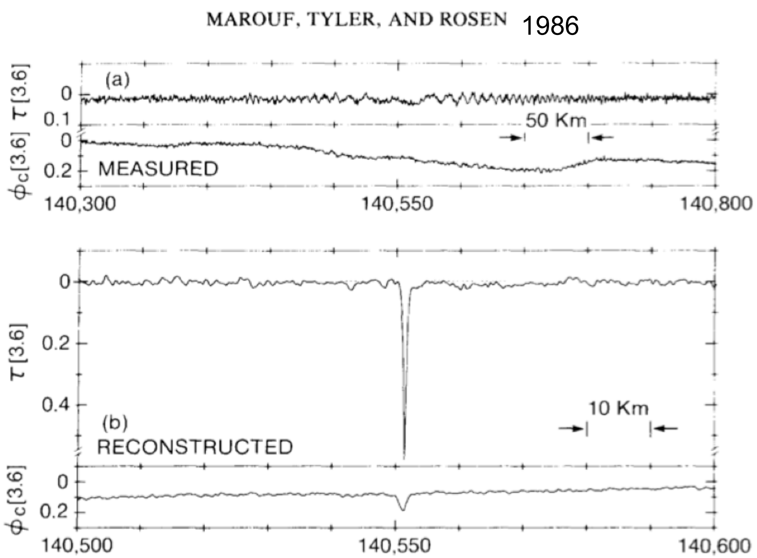
Resonance locations near the F Ring

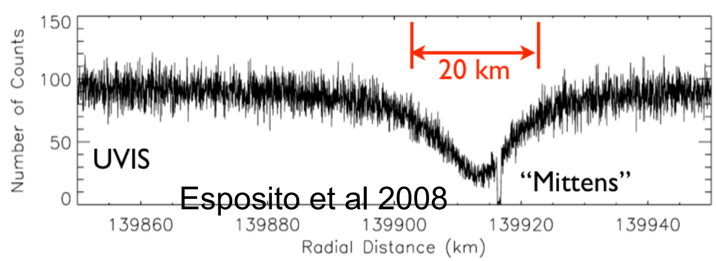


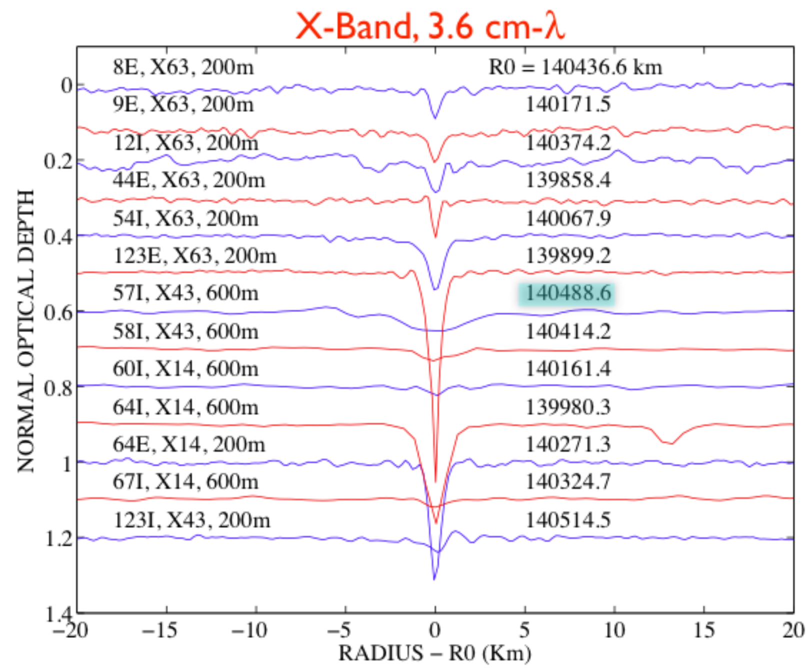
RSS sees a different F Ring core

Marouf et al. 2011 a,b

- ✓ RSS core ~0.1-1km wide, *vs* ISS/UVIS/VIMS “core” tens of km
- ✓Comparable optical depth at K, X, S bands (> few cm radius)
- ✓ Not always detected! (15 of 49 in 2011; 24 of 67 to date)







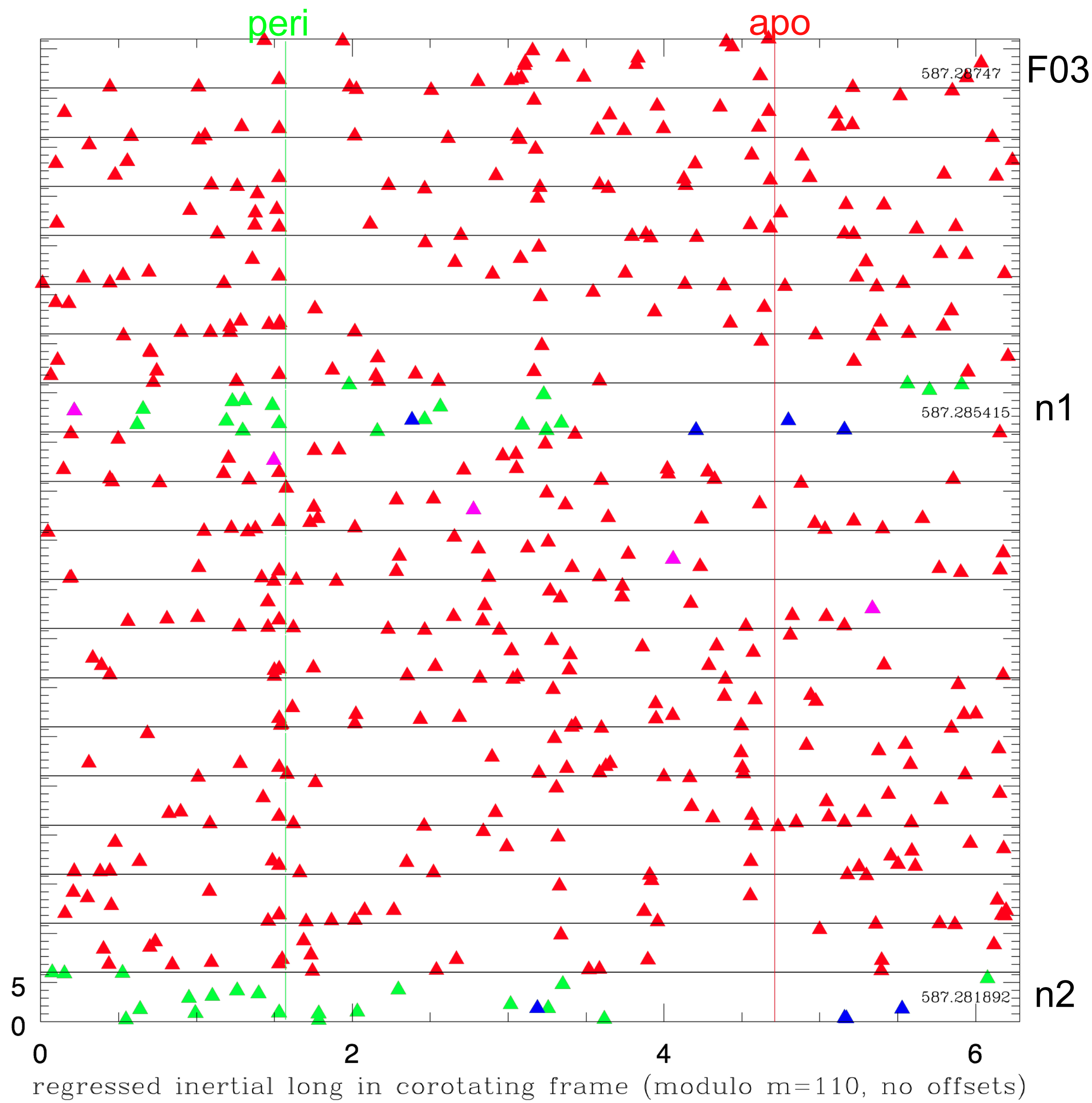
Are the RSS occultations consistent with CR idea?

- Start with inertial longitudes of 23 Cassini RSS detections, VGR1 RSS detection, and 43 Cassini RSS nondetections. No discrimination by optical depth of detection.

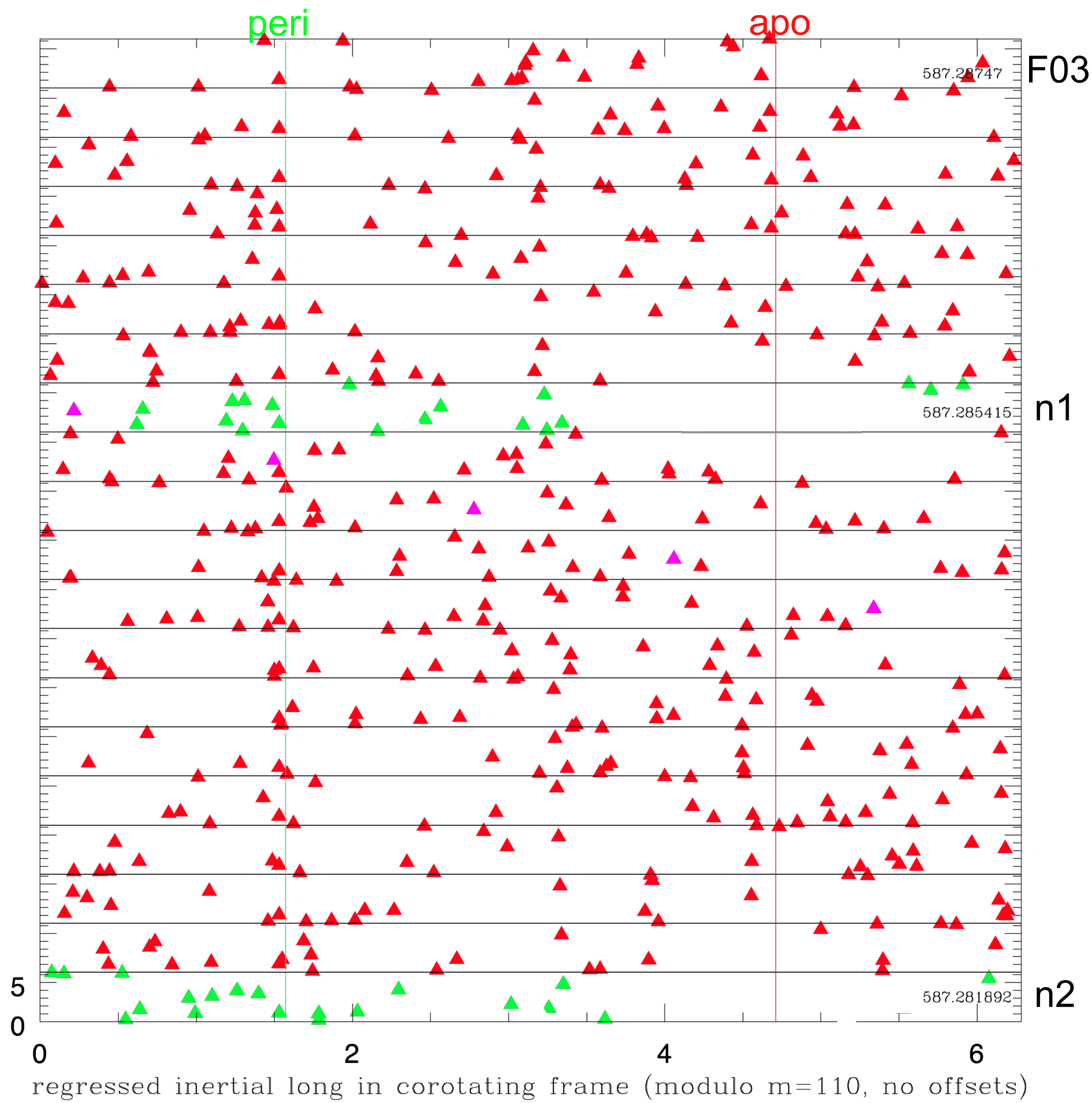
- Regress to some epoch on comb of candidate mean motions for *m*=110 CER, varying n_{Pr} in fractional steps of 5E-7 (0.07km), and then fold resulting longitudes mod (360/110)^{o}.

- Look for clustering in a restricted range of folded longitudes *near* (regressed and folded) Prometheus periapse and *away from* its apoapse. Use Jacobson's avg. value for Prometheus apse precession, starting with longitude of Cooper et al (2012).

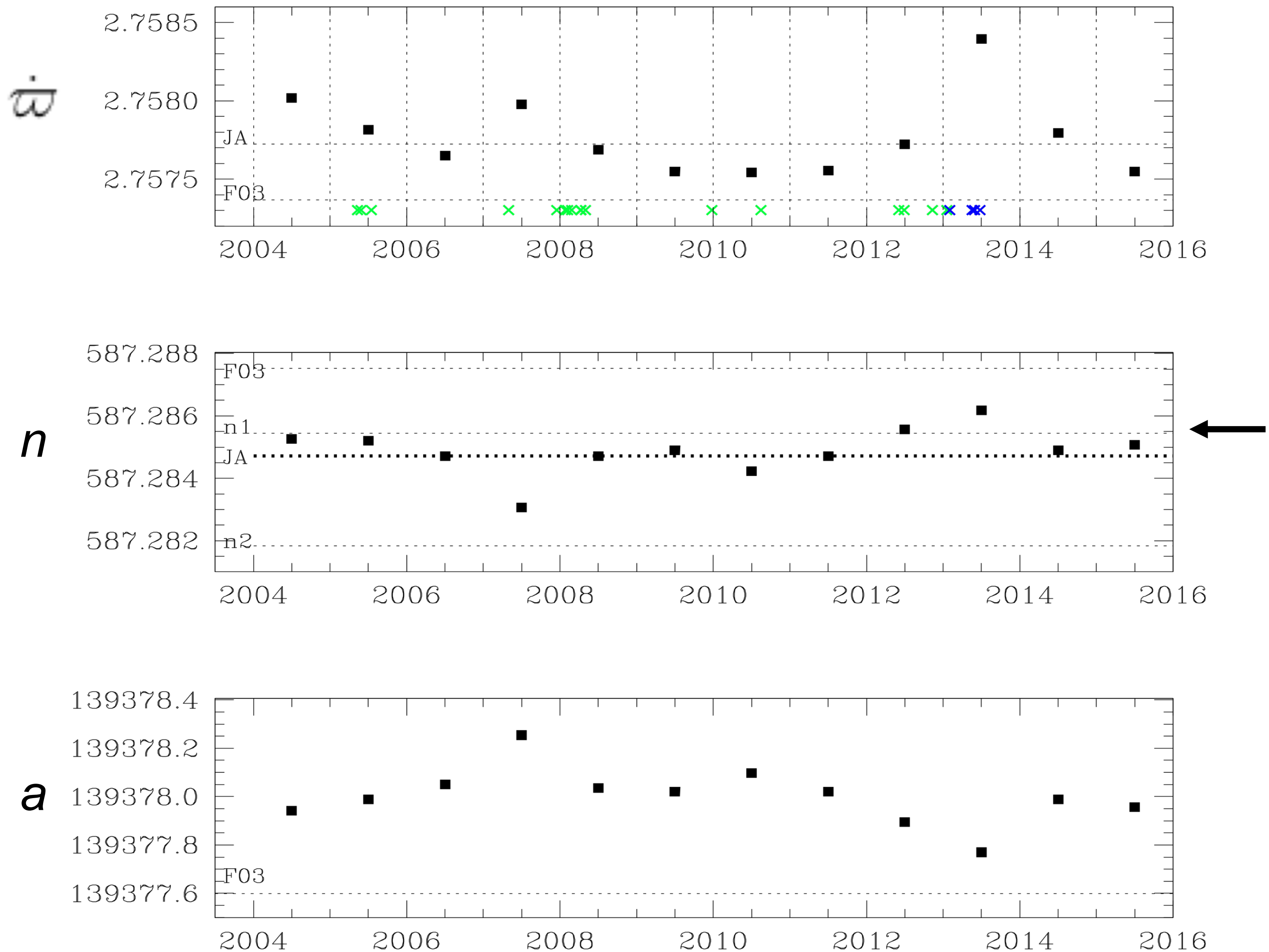
Panels show regressed and folded longitudes of RSS detections assuming F Ring Core at m=110 CER, by stepping Prometheus mean motion *in steps of $\Delta n/n$=5E-7*

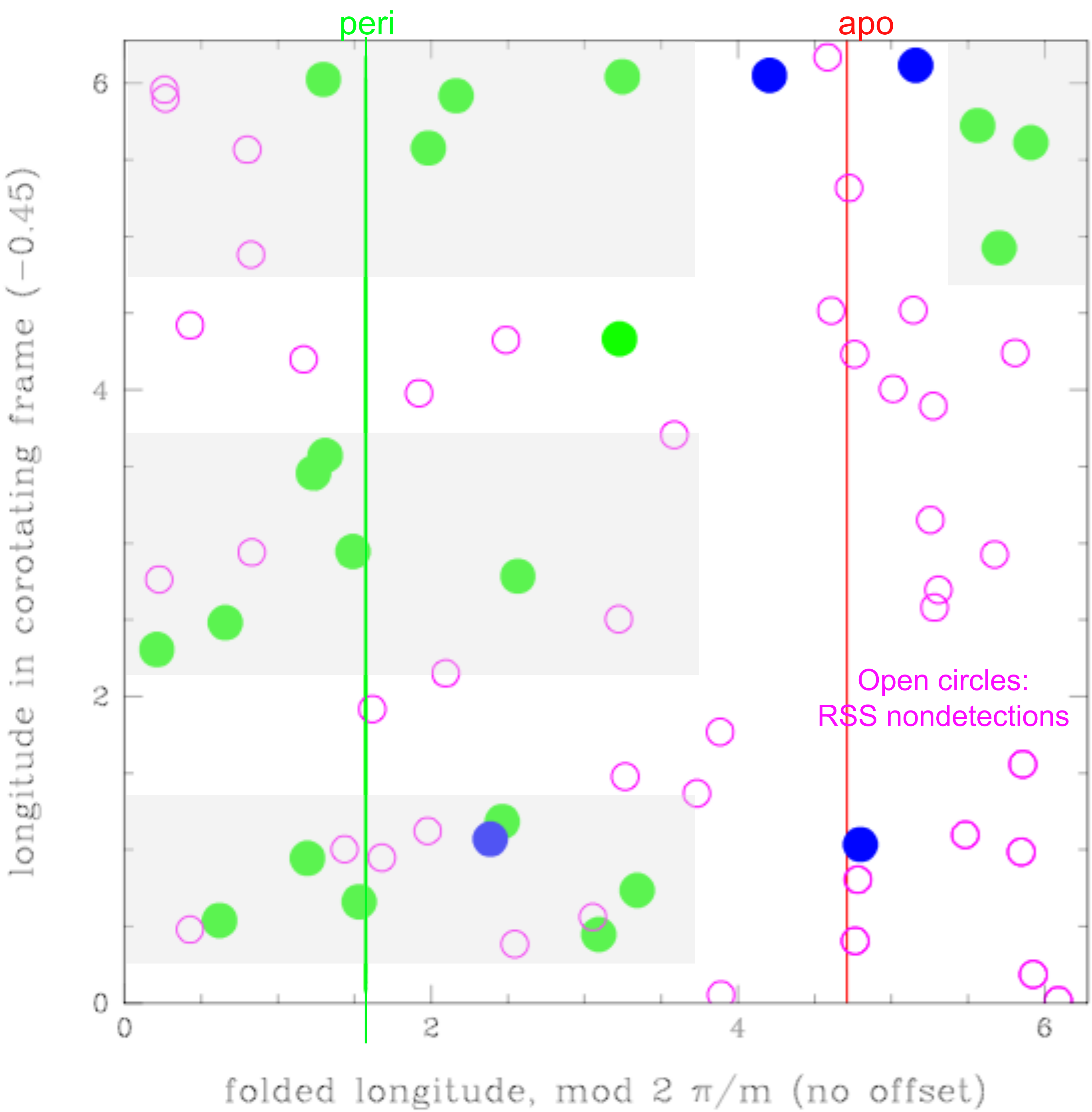


Panels show regressed and folded longitudes of RSS detections assuming F Ring Core at m=110 CER, by stepping Prometheus mean motion *in steps of Δn/n=5E-7*



Uncertainty and variability in Prometheus' orbit




peri
apo
Open circles:
RSS nondetections
longitude in corotating frame (−0.45)
folded longitude, mod 2 π/m (no offset)
0
2
4
6
0
2
4
6

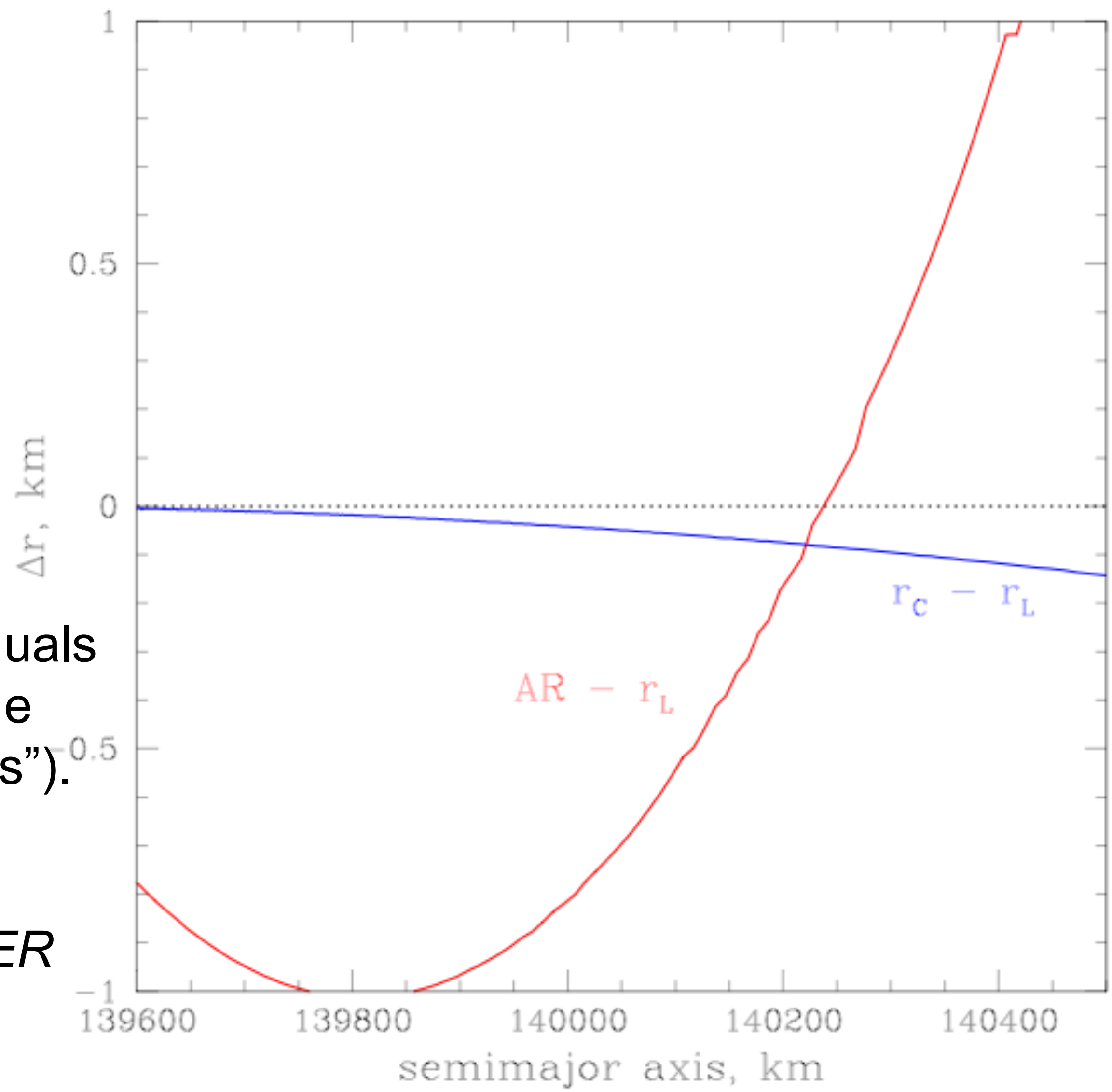
Relative offset between (ARs, CERs) and OLRs

ARs and CERs are always very close to OLRs - within 1km across the entire region

CERs always inside OLRs, asymptotically overlapping; ARs sometimes inside, sometimes outside

Hard to tell from SMA-residuals which is actually responsible for stable zones (“stalactites”).

However, there is only one place where the AR and CER exactly coincide. . . . . .

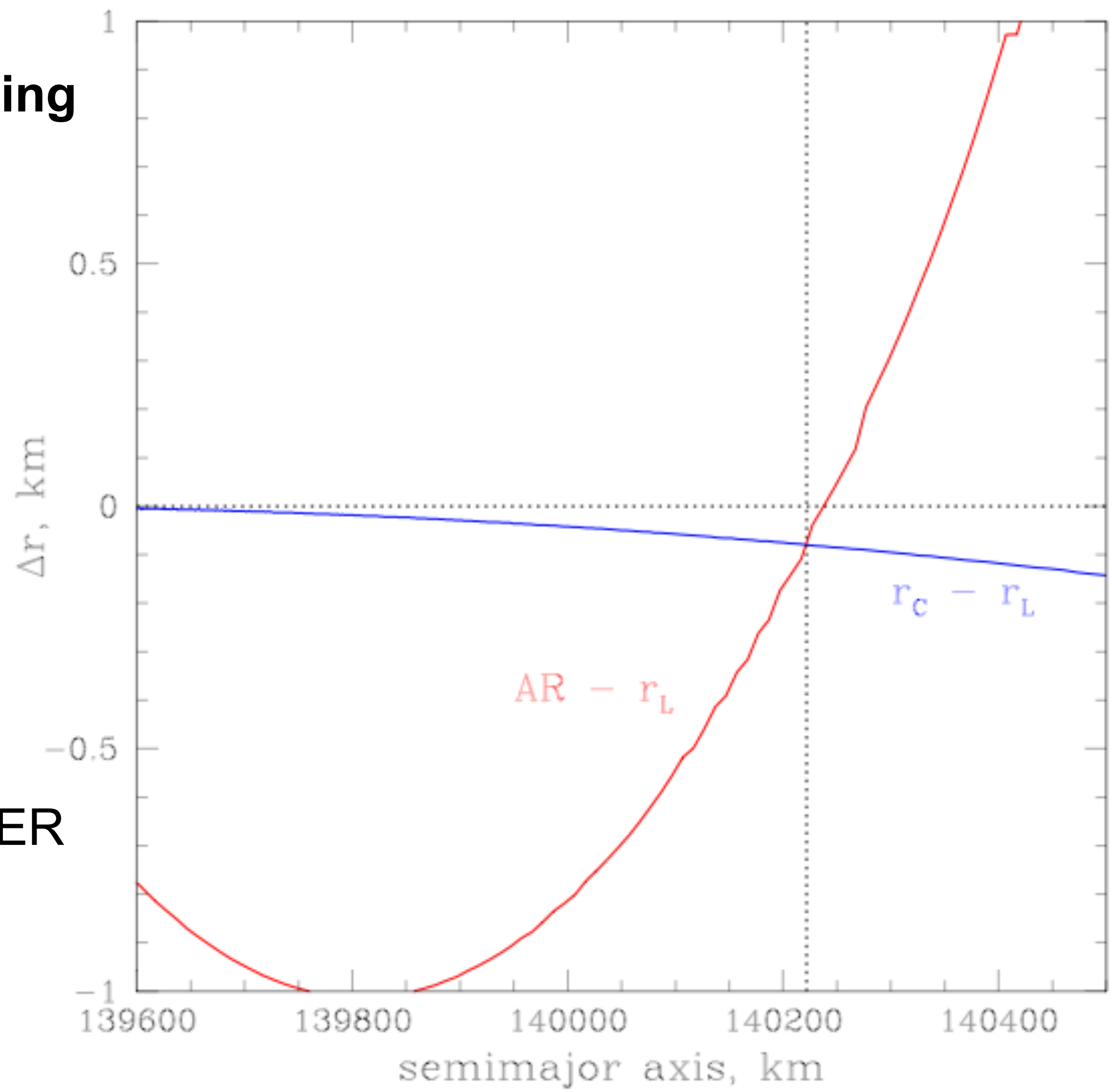


Relative offset between (ARs, CERs) and OLRs

…..exactly where the F Ring core lies (140222.4km)!

It cannot be a coincidence that the F Ring core lies in the only place in the entire F Ring region where the AR and the CER exactly coincide.

Most likely, *both* AR and CER are required for long term stability.



Summary

F Ring stability is due to a *combination* of "antiresonance" (AR) associated with Prometheus' *m*=109 OLR, *and* its *m*=110 CER. AR is the result of rapid precession of Prom apse, and the long synodic period between Prometheus and an F Ring particle.

Some dramatic change in Prometheus' (and Pandora's) orbits in early 2013 has disturbed the pattern of stable sites. Stable sites may be concentrated in three longitudinal segments.

F Ring SMA = 140222.4 +/- 0.1 km from 2005-2013 at least; however, it must "breathe" over time as Prometheus orbit varies.

F Ring core must be able to *track* these small modifications to the orbit of Prometheus in order to maintain long-term stability. Stable sites act as "attractors" for wayward particles, perhaps allowing this to happen.