Deciphering the Embedded Wave in Saturn's Maxwell Ringlet

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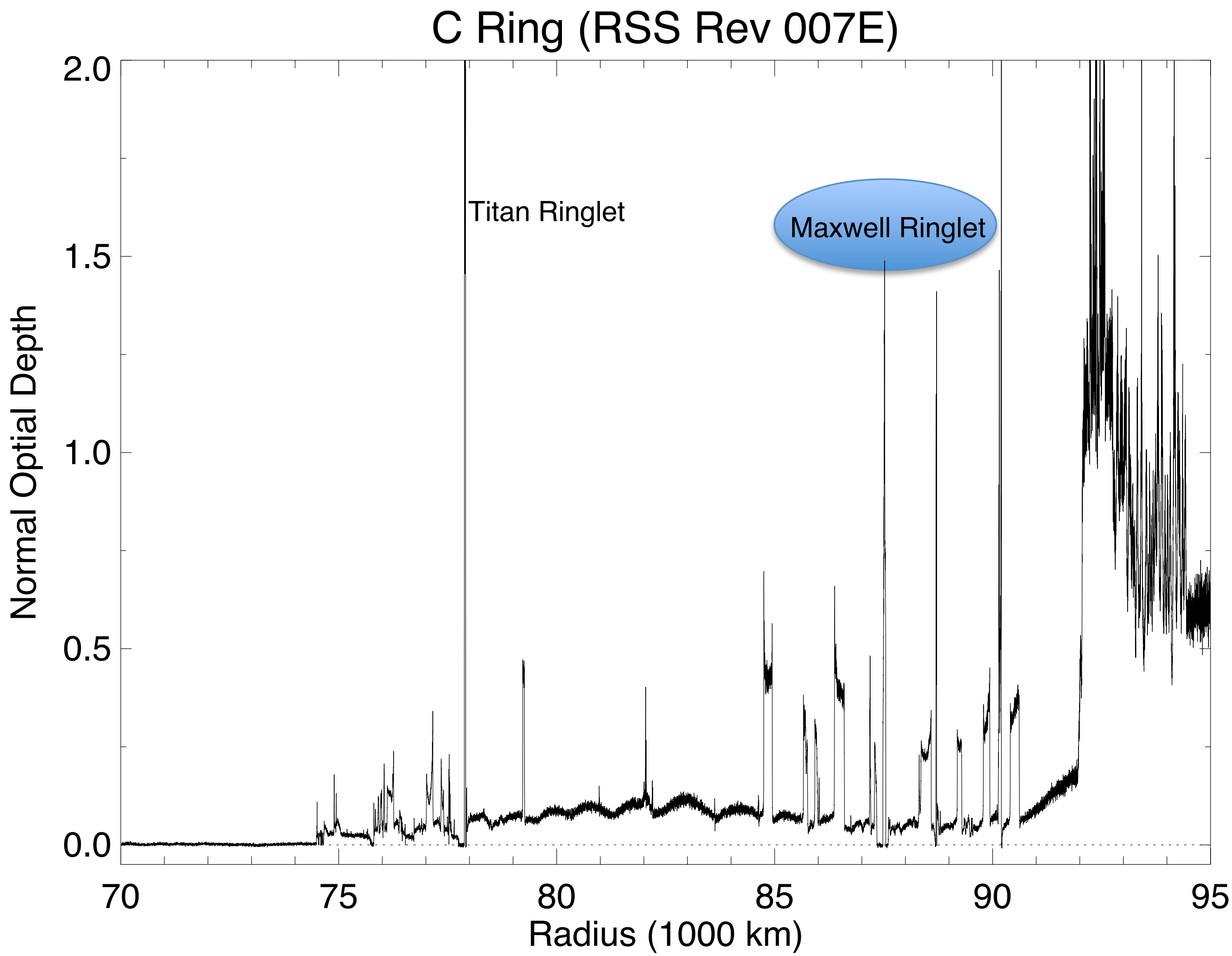
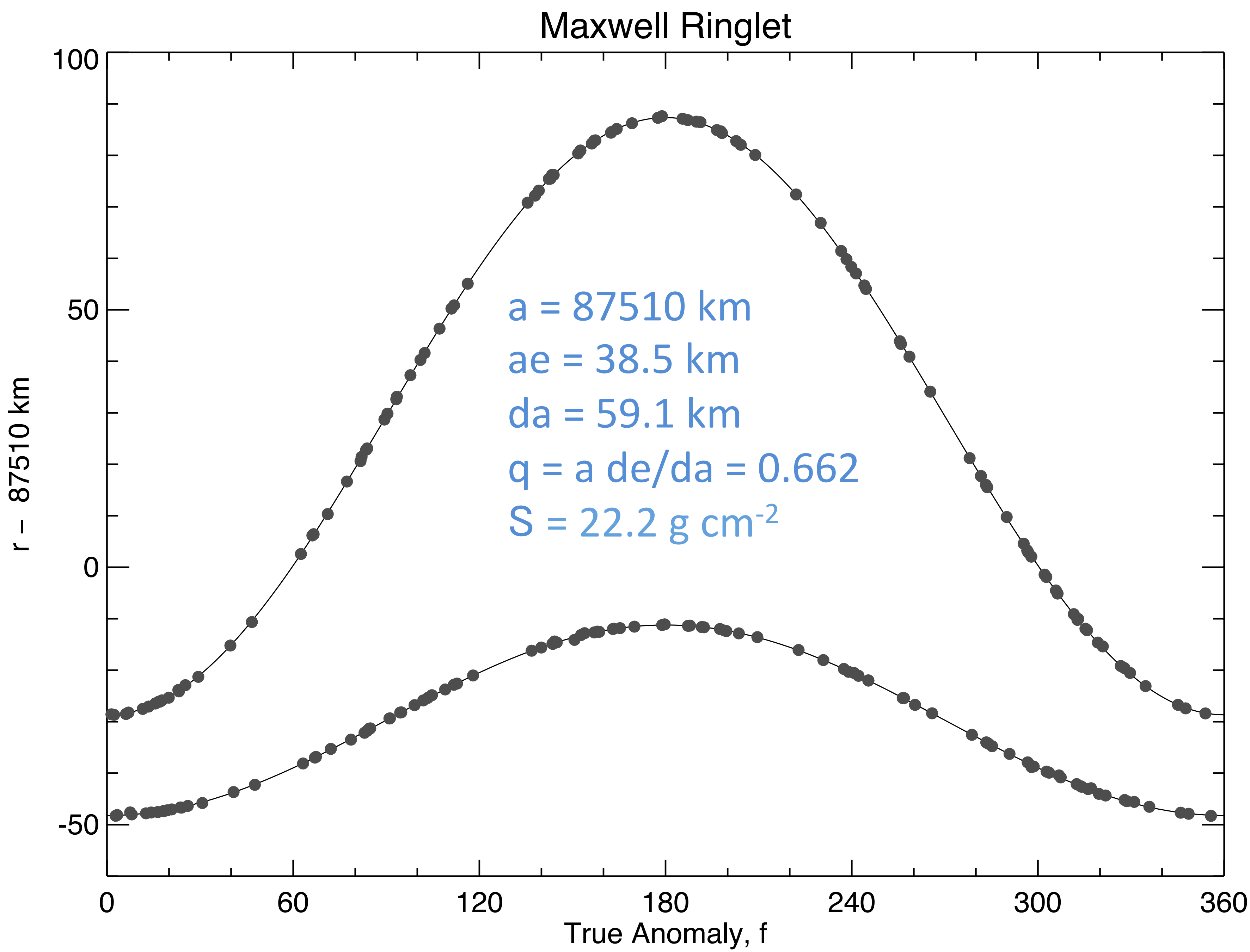
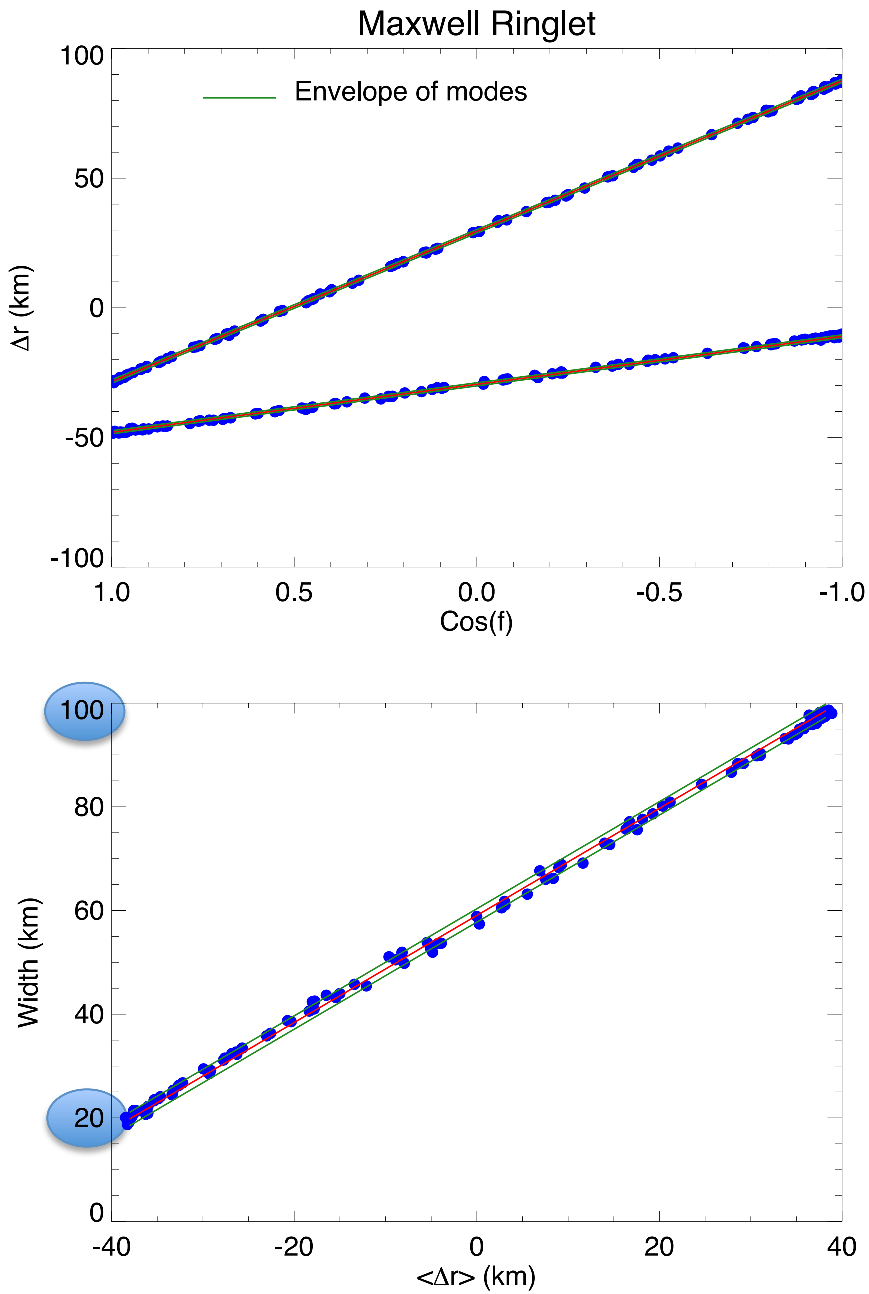

C Ring (RSS Rev 007E)
Titan Ringlet
Maxwell Ringlet
Normal Optial Depth
2.0
1.5
1.0
0.5
0.0
70
75
80
85
90
95
Radius (1000 km)



Maxwell Ringlet
100
50
0
-50
r – 87510 km
0
60
120
180
240
300
360
True Anomaly, f
a = 87510 km
ae = 38.5 km
da = 59.1 km
q = a de/da = 0.662
S = 22.2 g cm-2



Inner edge:

a = 87480.29 km

ae = 18.93 km

rms = 0.23 km

N = 105

Outer edge:

a = 87539.36 km

ae = 58.02 km

rms = 0.16 km

m = 2: ae = 0.19 km

m = 4: ae = 0.29 km

N = 105

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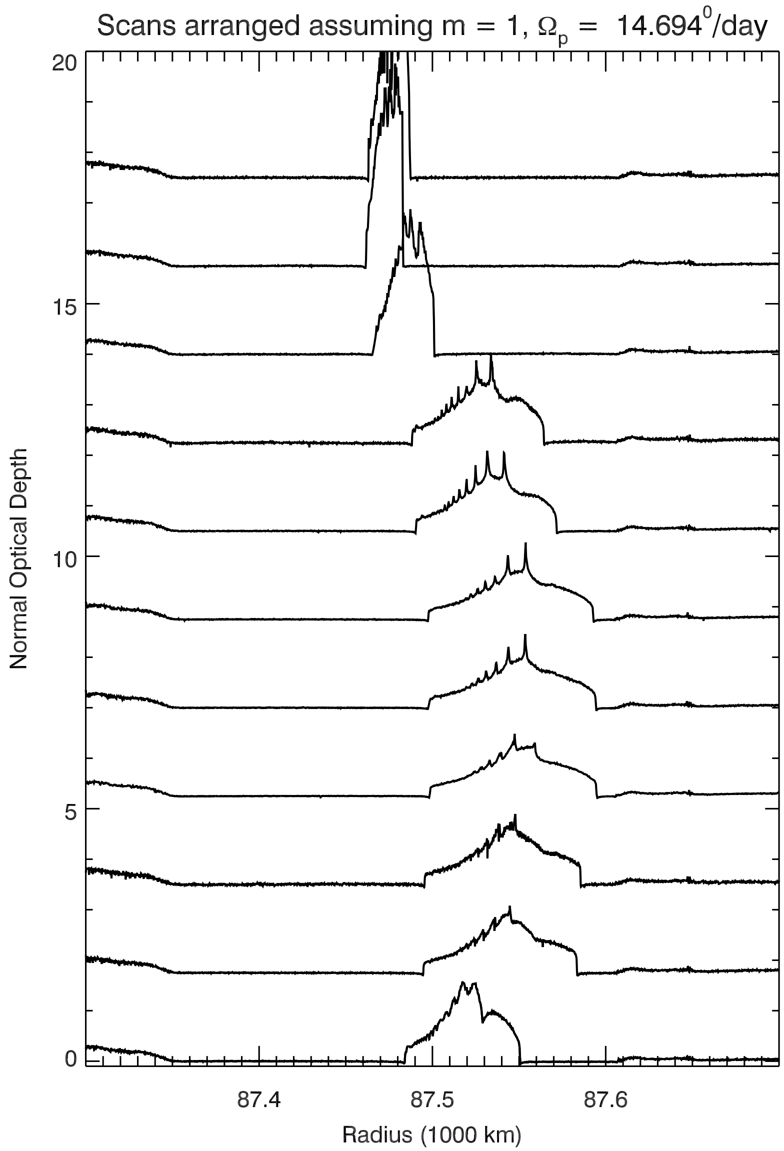
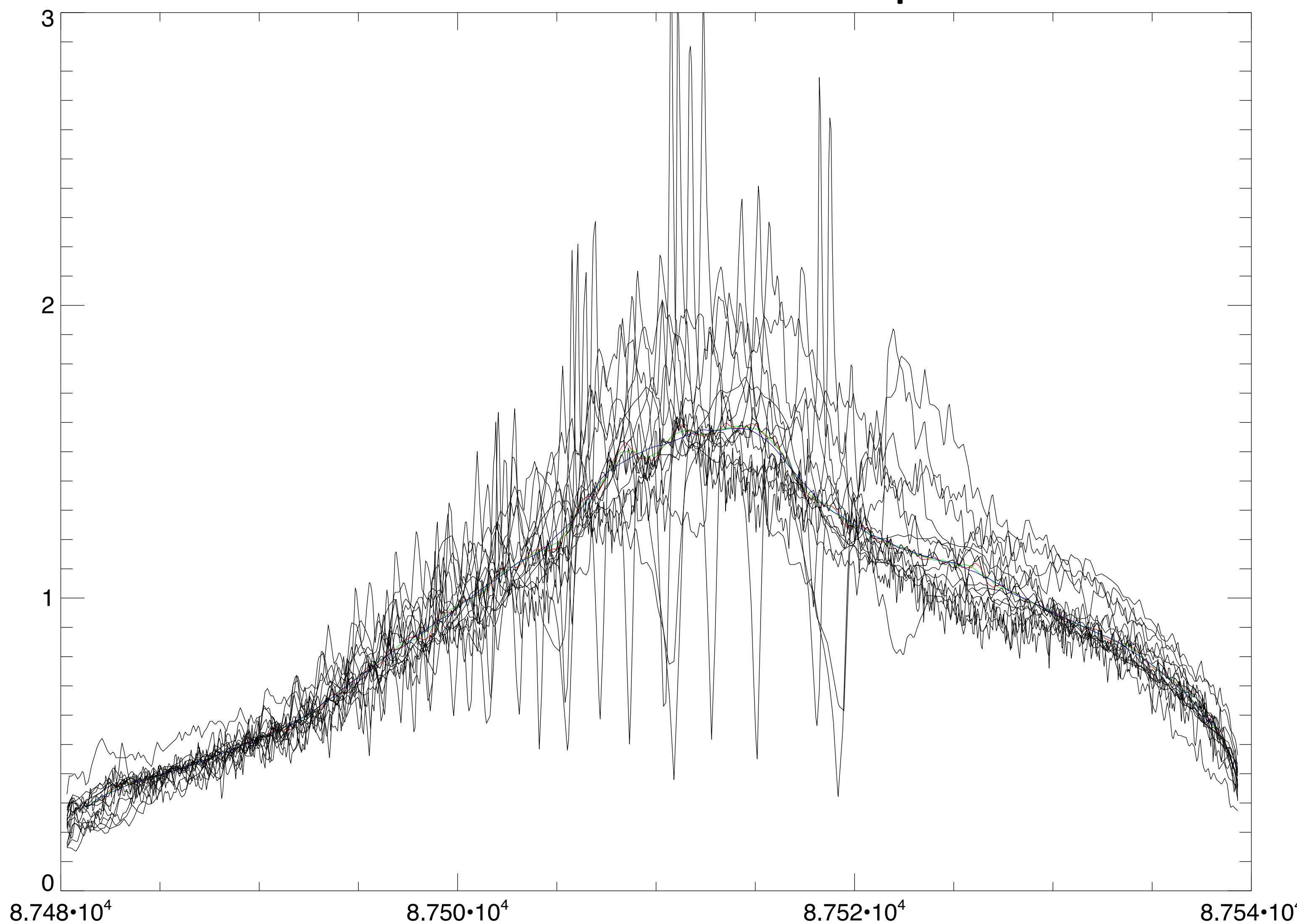
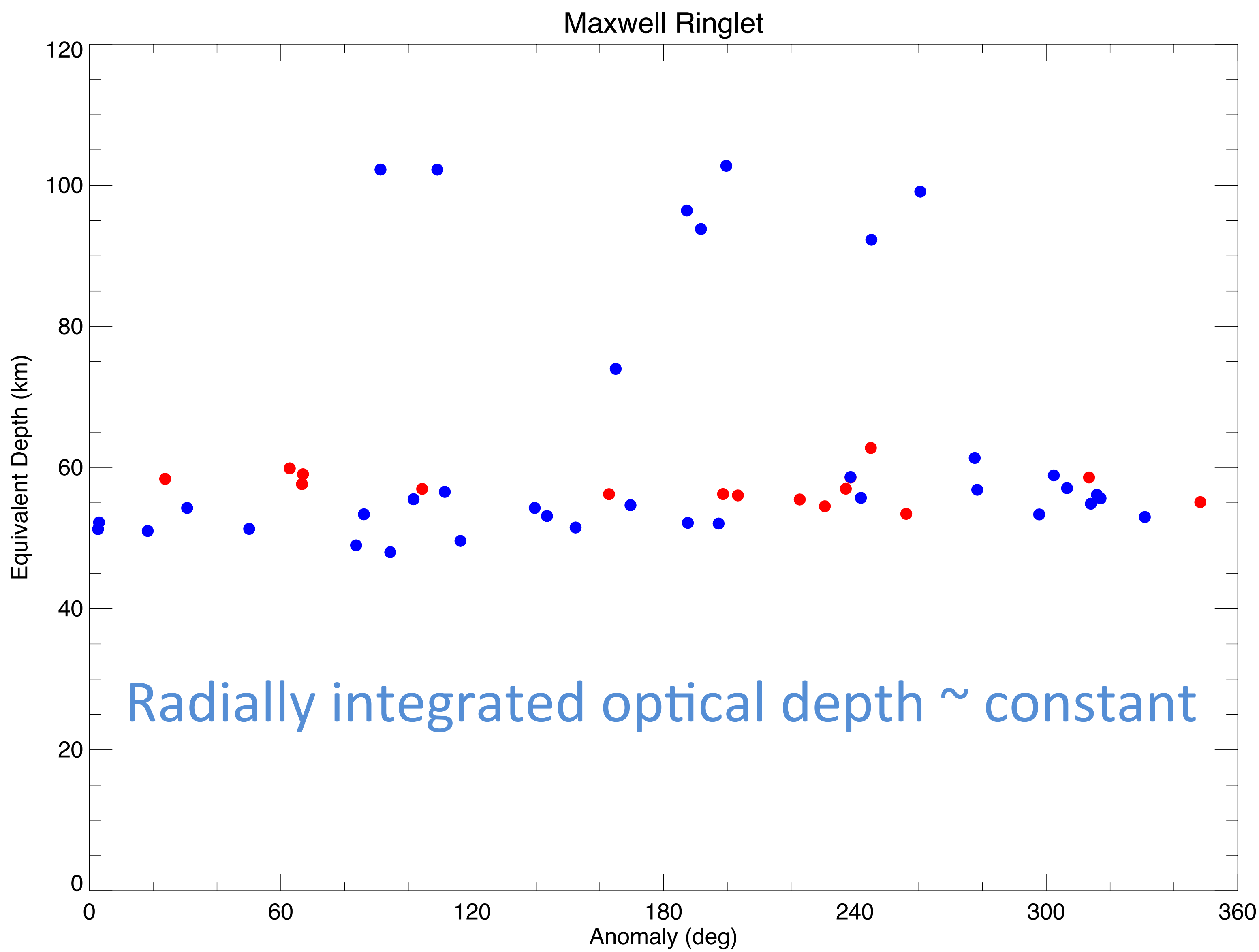


- Ring profiles sorted by true anomaly
- prominent wave in inner half

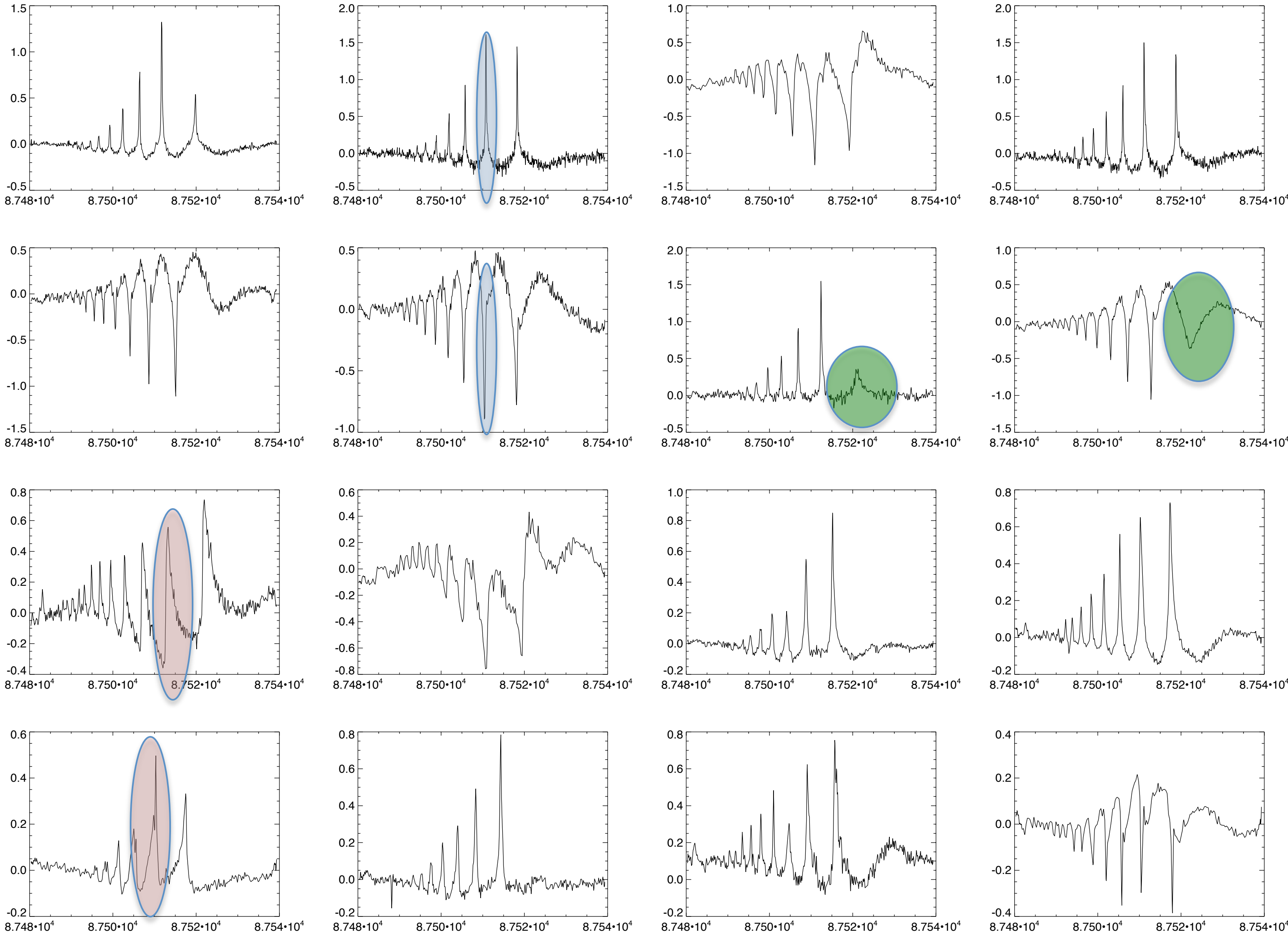
“Accordion” stack of radial profiles

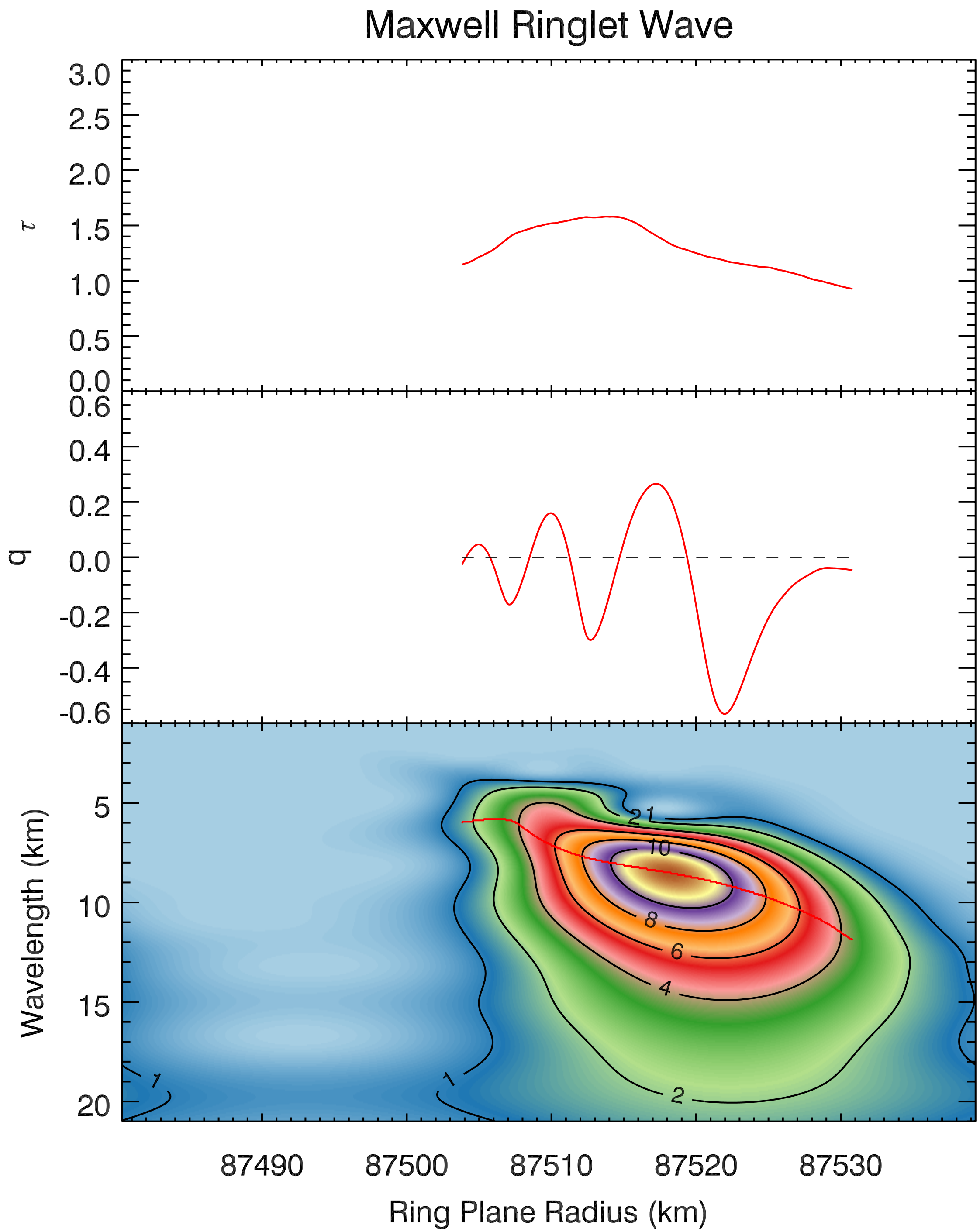




Maxwell Ringlet
Equivalent Depth (km)
Anomaly (deg)
0
20
40
60
80
100
120
0
60
120
180
240
300
360
Radially integrated optical depth ~ constant

Background-subtracted profiles: variable structure

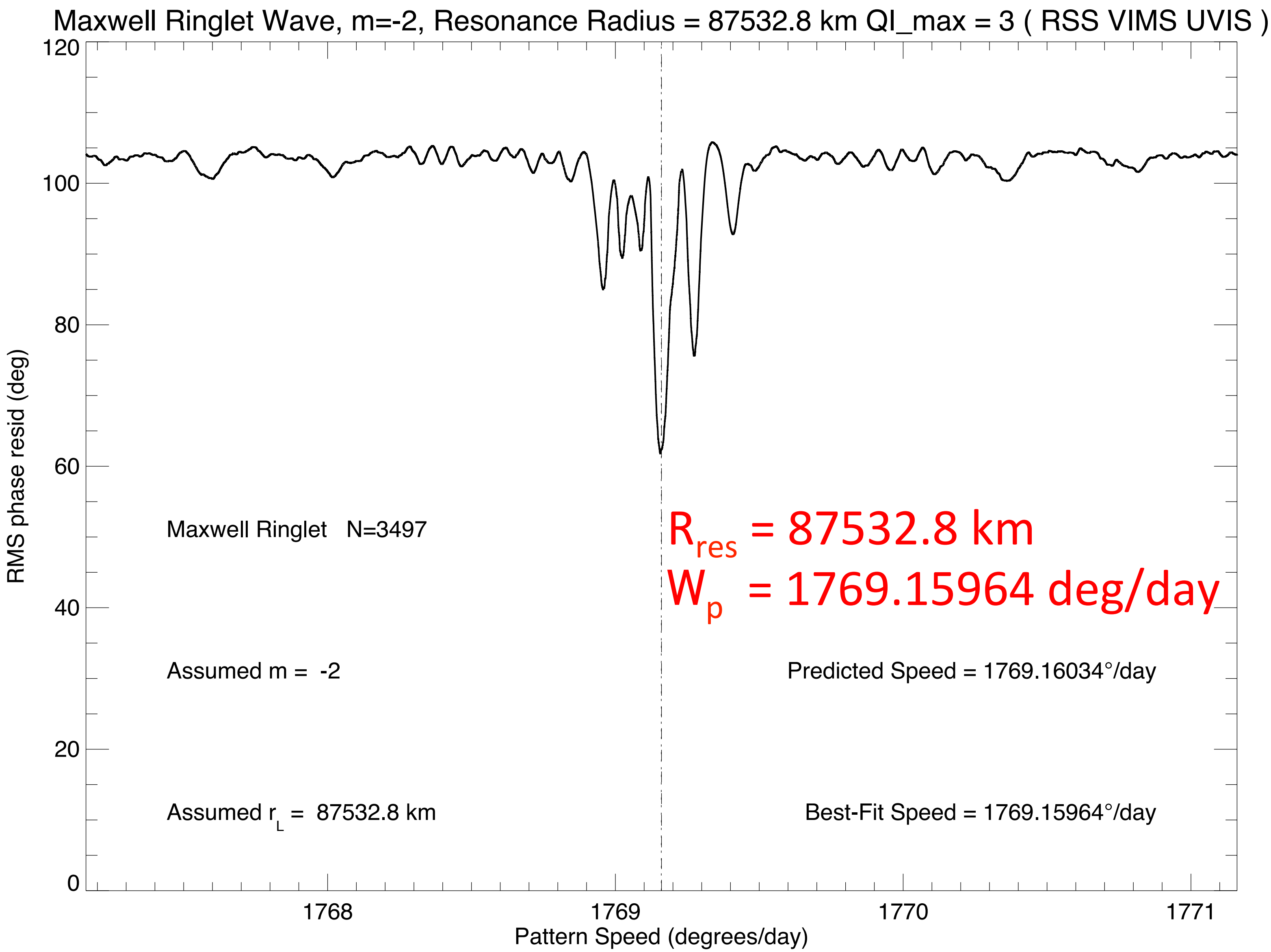




Wavelet decomposition used to determine wave phase and wavenumber

l = 5 – 10 km

Detection of m=2 Outer Lindblad Resonance Wave



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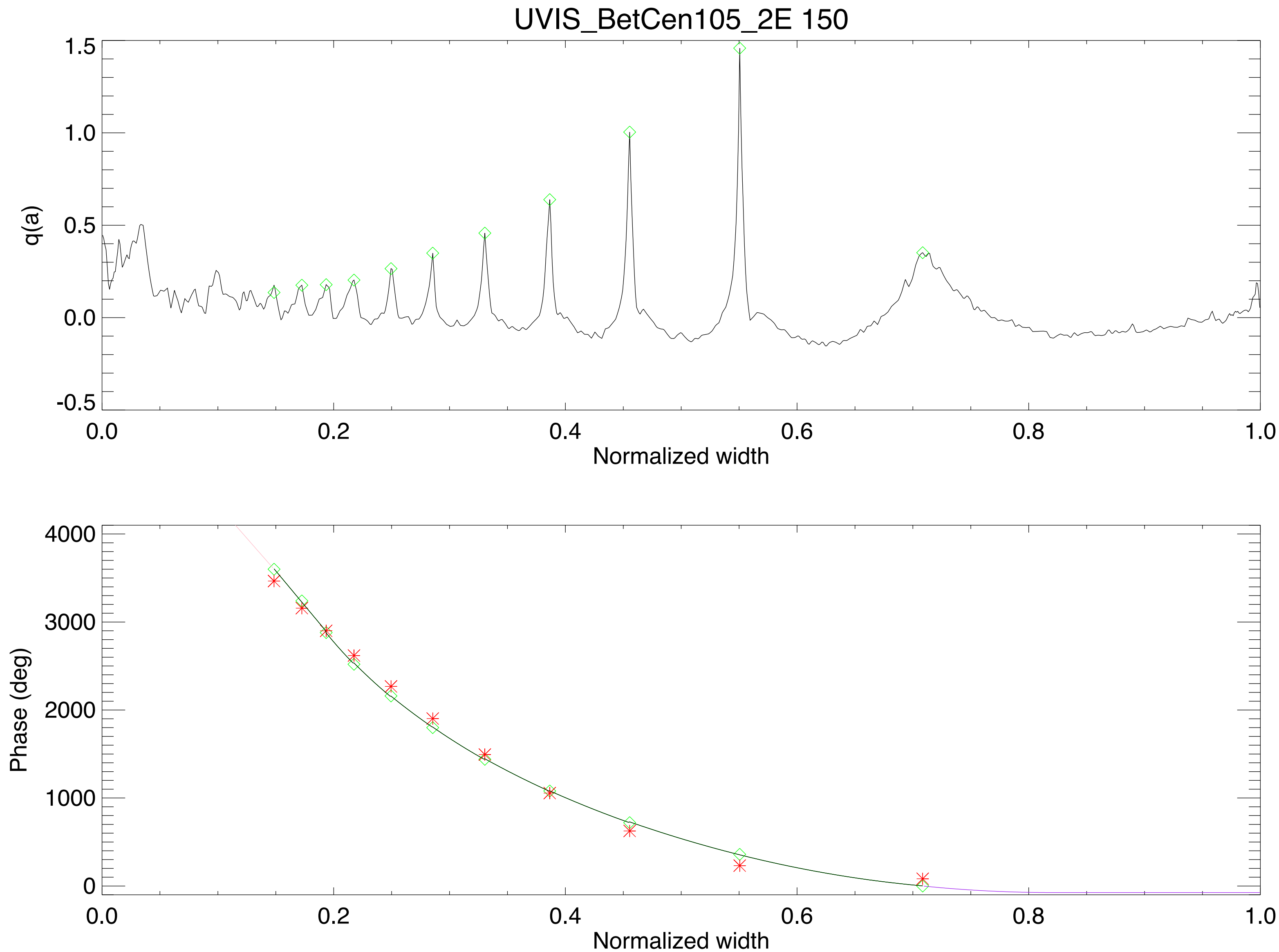
Determination of wave phase vs normalized width



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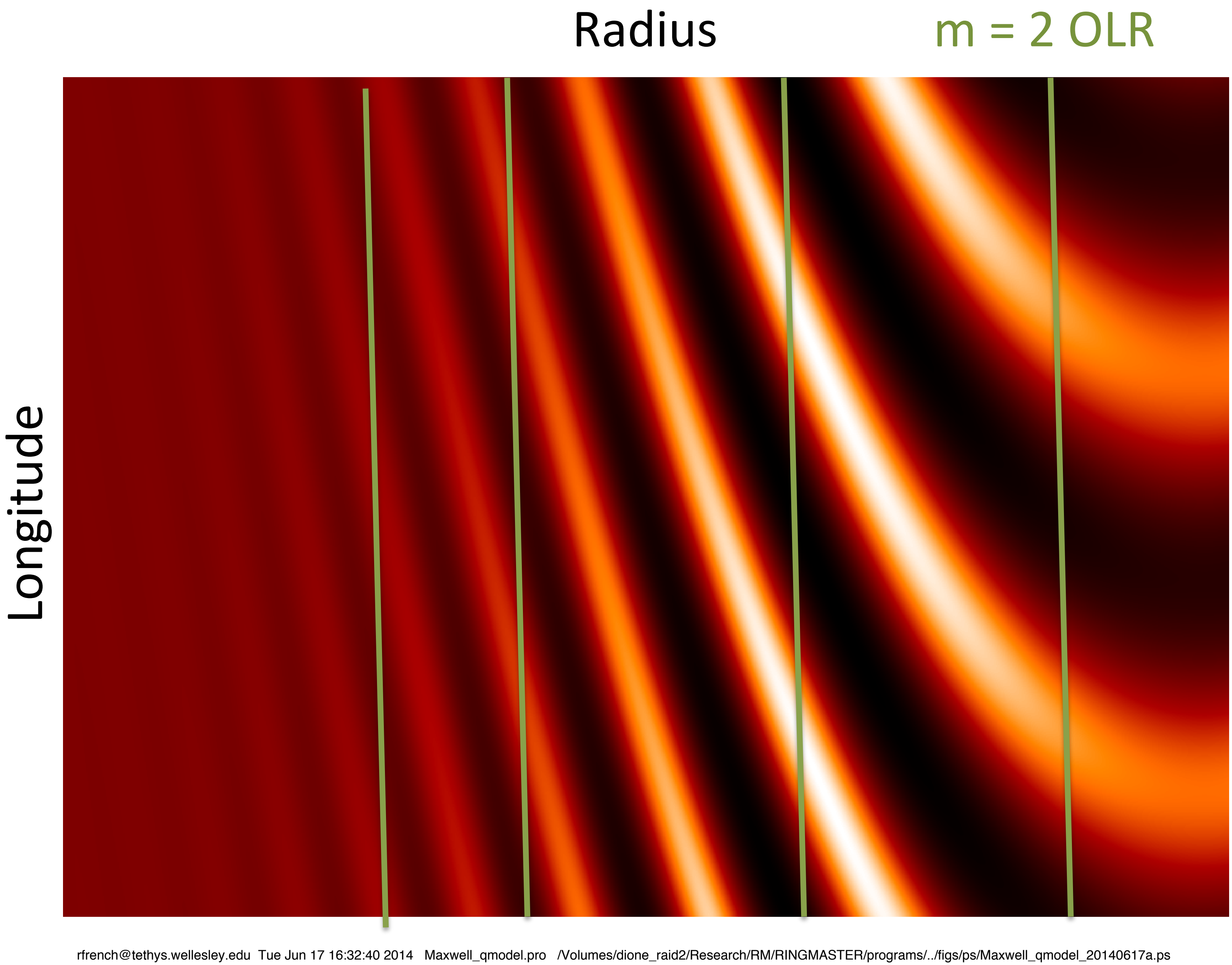
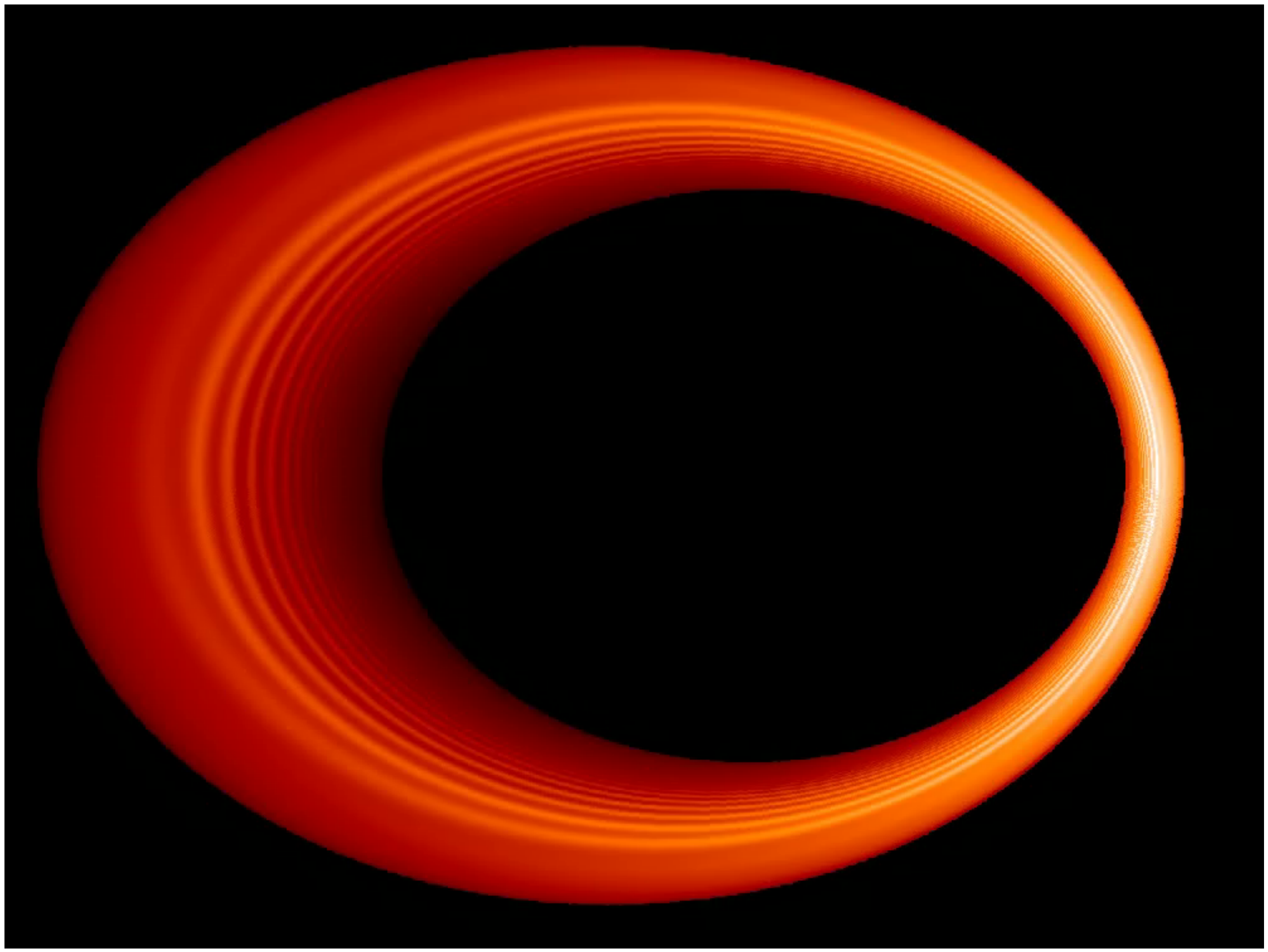
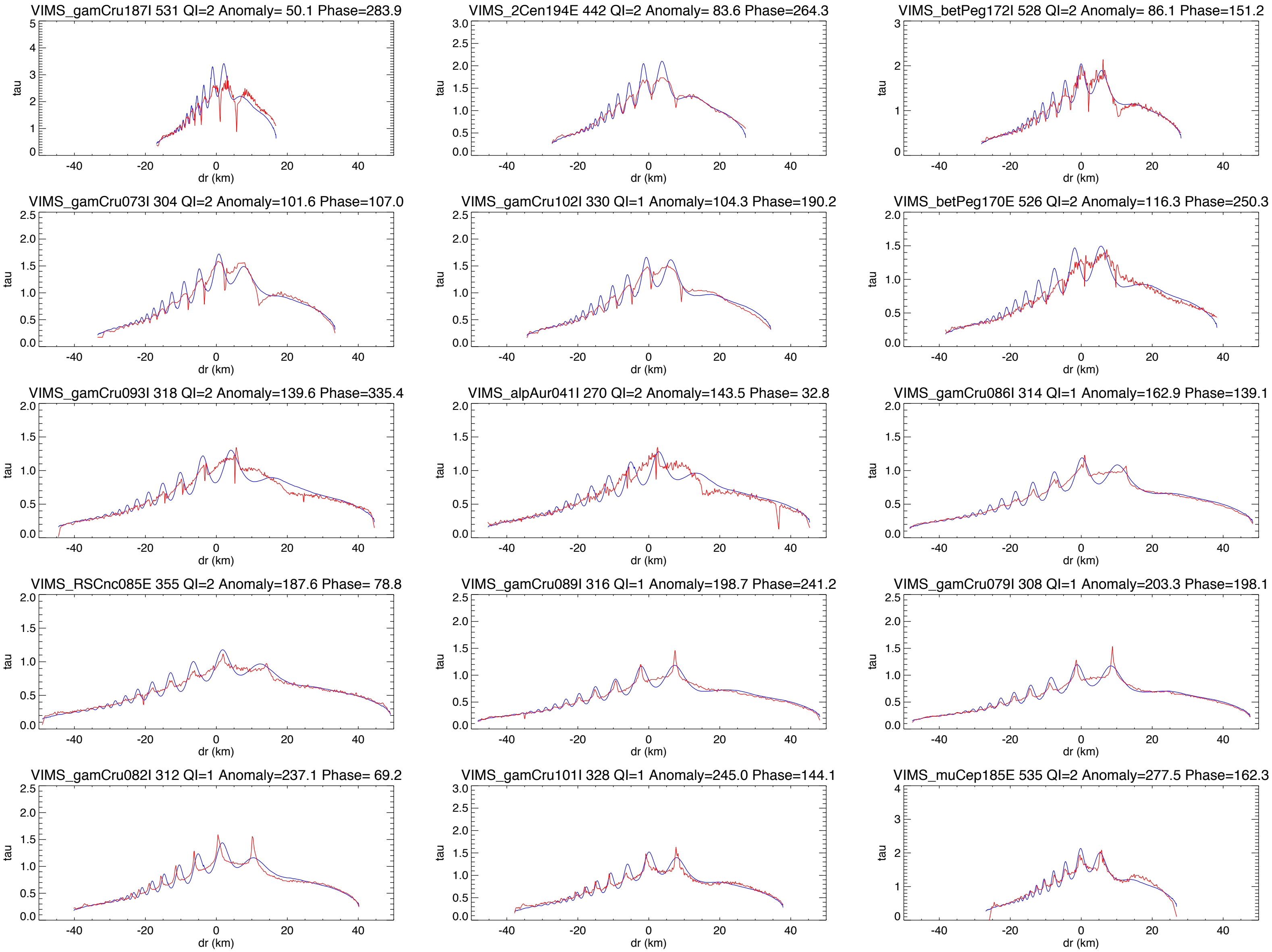

Radius
m = 2 OLR
Longitude
rfrench@tethys.wellesley.edu Tue Jun 17 16:32:40 2014 Maxwell_qmodel.pro /Volumes/dione_raid2/Research/RM/RINGMASTER/programs/../figs/ps/Maxwell_qmodel_20140617a.ps

Linear m=2 OLR density wave model



Linear density wave + “accordion” – matches phases of wave crests, but not shape



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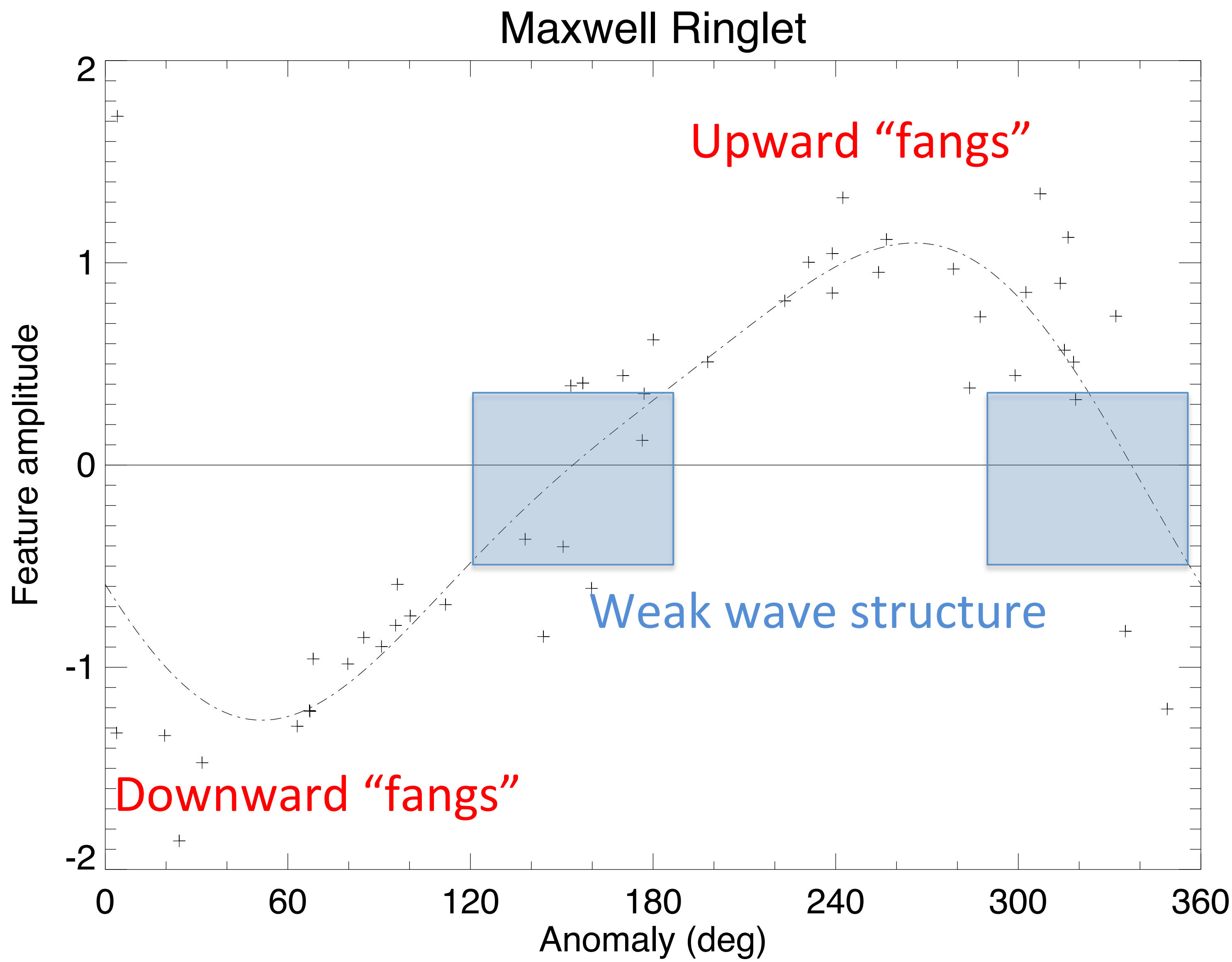

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So far:

+ Secure identification of m=2 OLR
+ Wave phase vs radius
+ Pattern speed
+ “Accordion” model works reasonably well

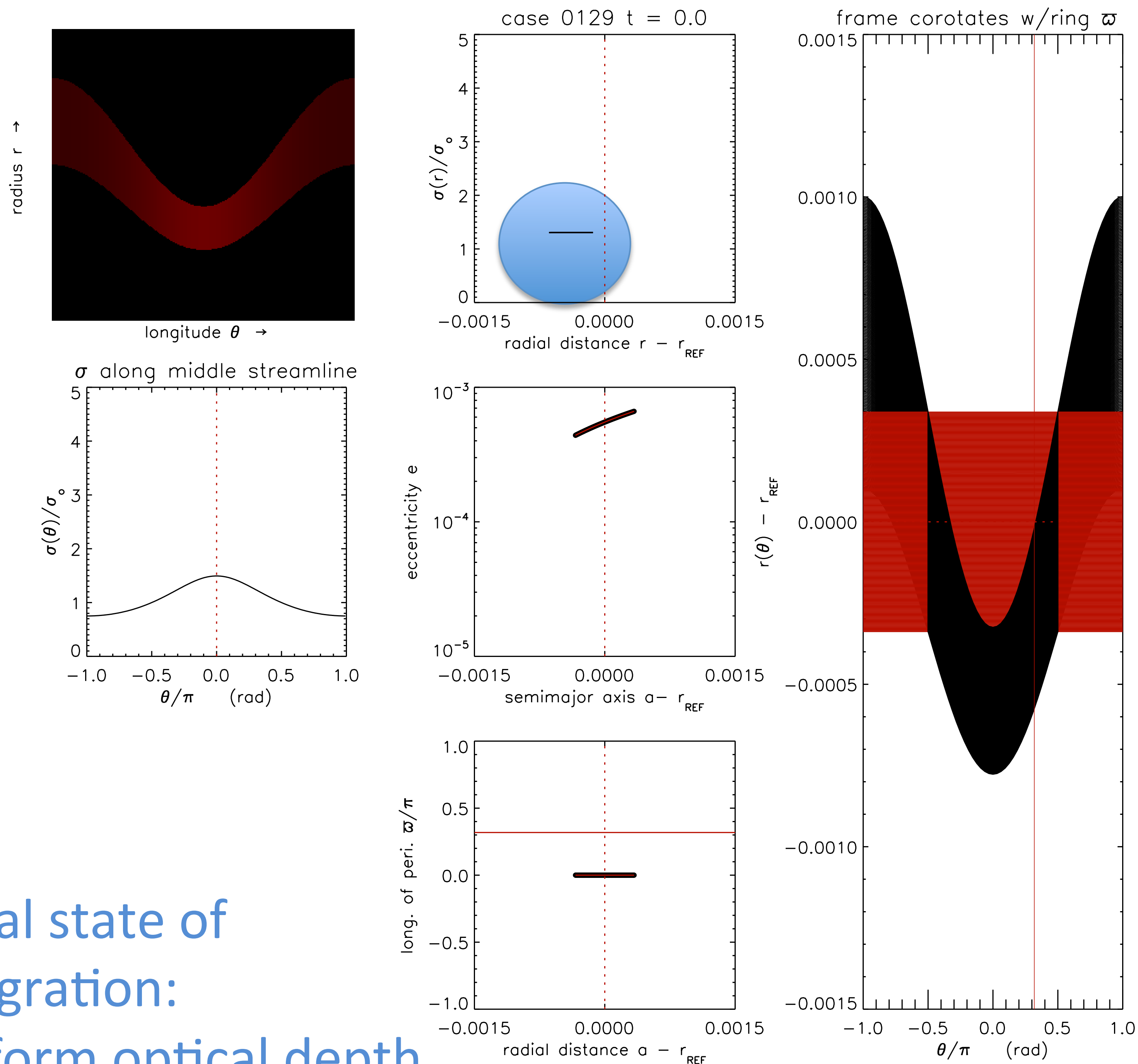
But…

- Linear wave model fails to match wave shapes
- No dynamics yet – purely kinematical model

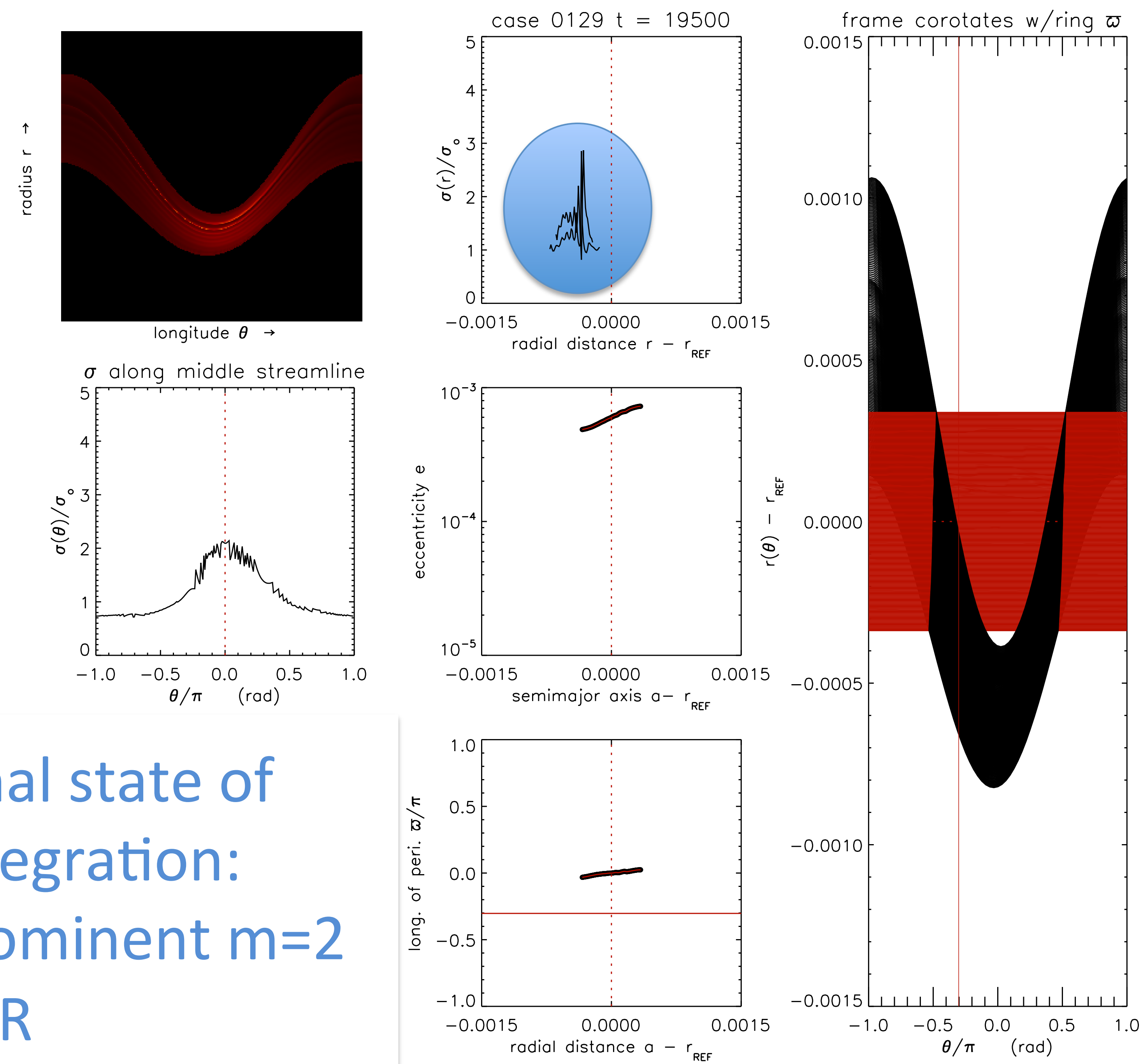
Next steps – dynamical models:

Hahn and Spitale (2013) –

- N-body symplectic integrator optimized for rings
- Streamline approach, includes self-gravity
- Accommodates J_2, eccentric ring edges
- Incorporates response to satellite forcing
- In principle, can model Maxwell Ringlet eccentricity + m=2 OLR driven by fictitious interior satellite
- Models evolve from initial state; takes time for wave to develop and cross the ring
- Nonlinear response included in the dynamics

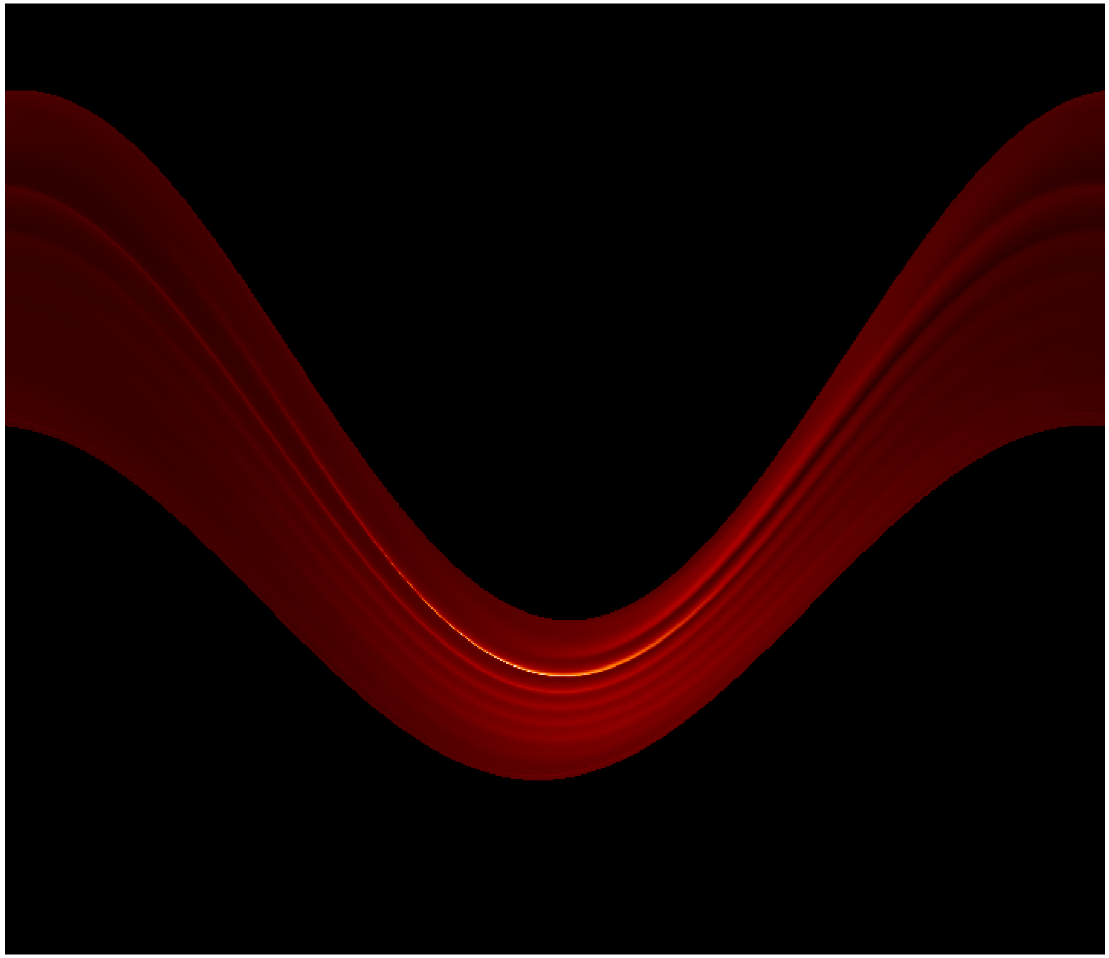


Initial state of integration: Uniform optical depth

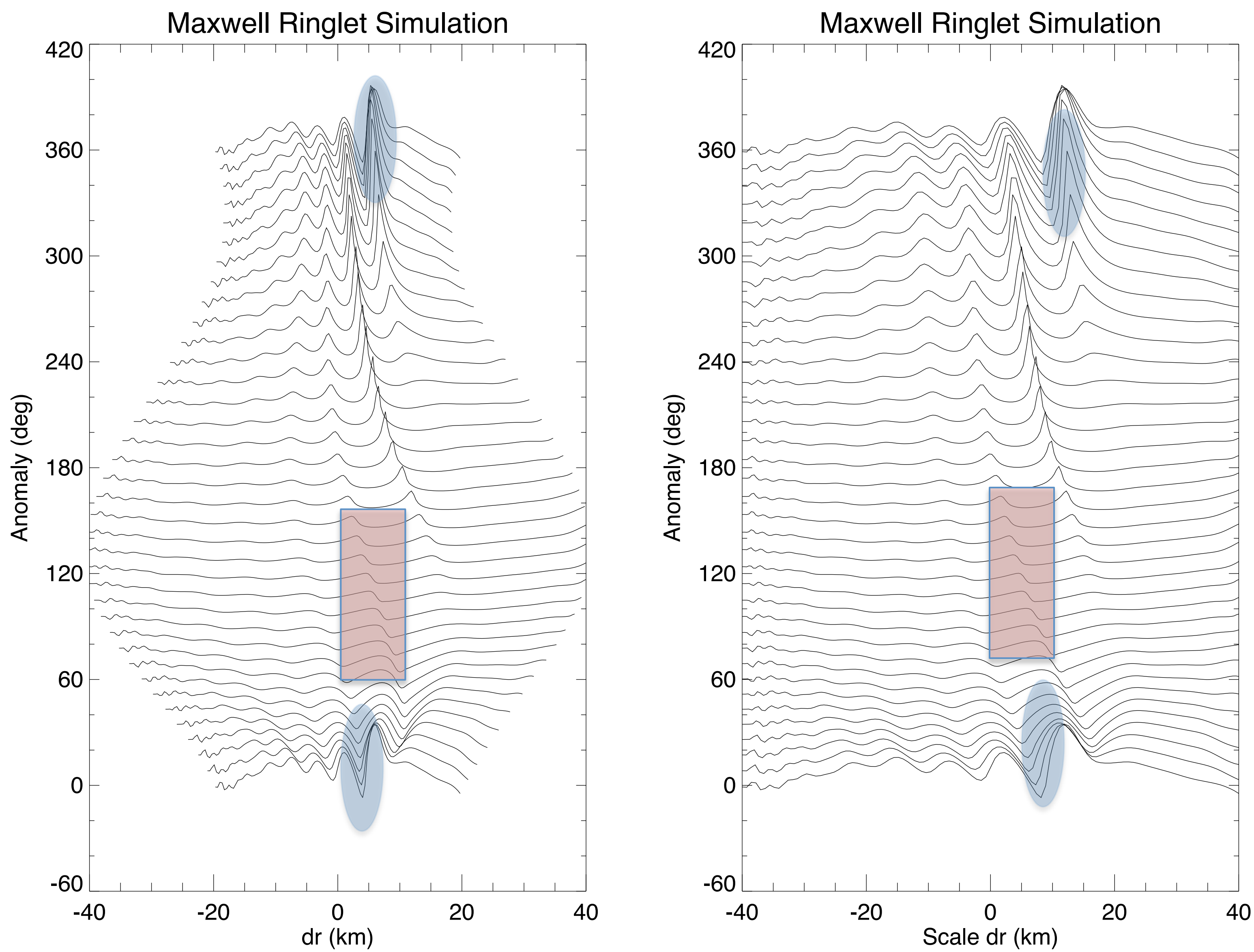


Final state of integration: Prominent m=2 OLR

Best model proceeds until streamlines cross and simulation halts



Non-linear features of actual observations are reproduced w/ Hahn/Spitale code



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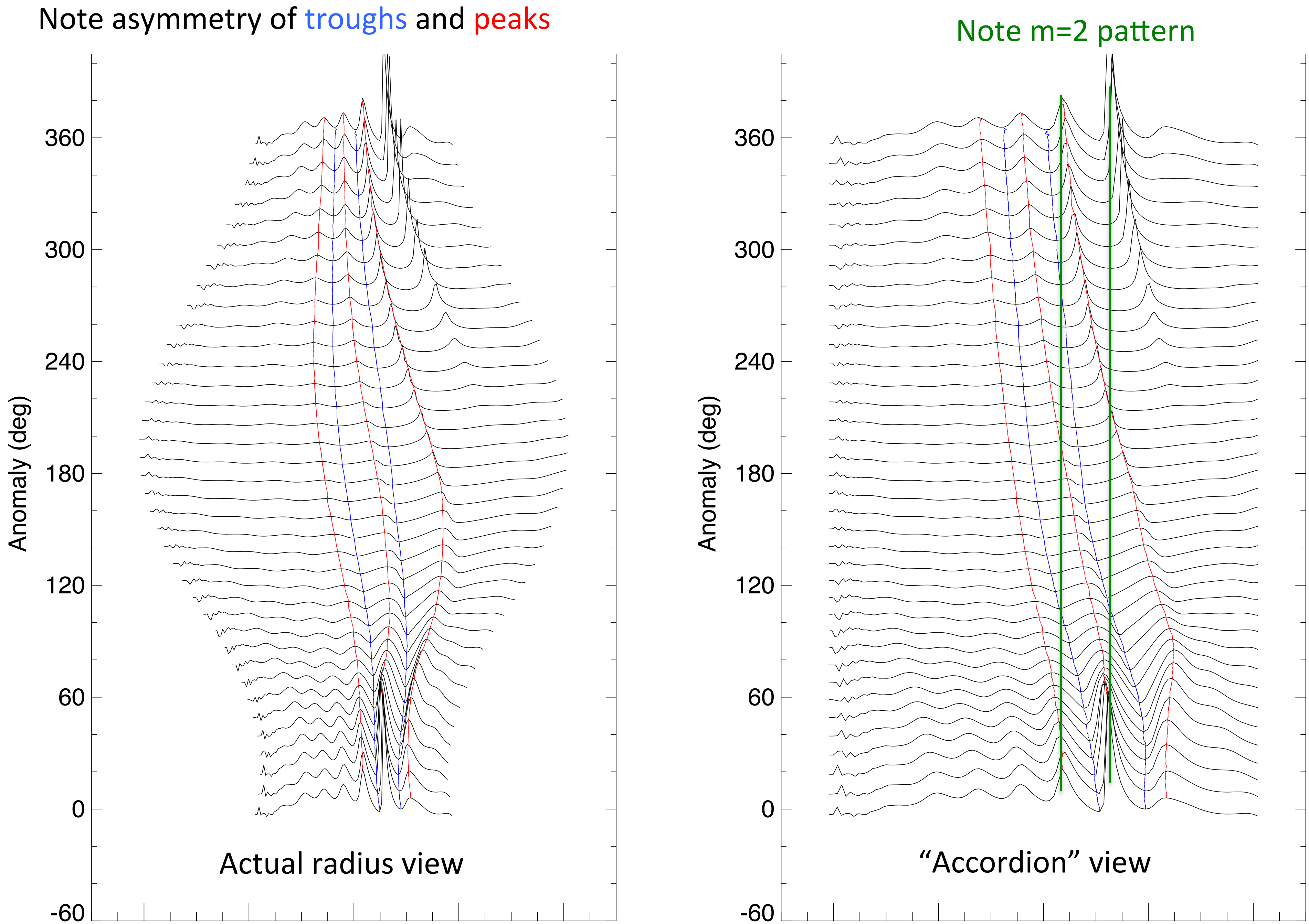


Note asymmetry of troughs and peaks
Note m=2 pattern
Anomaly (deg)
360
300
240
180
120
60
0
-60
Actual radius view
"Accordion" view

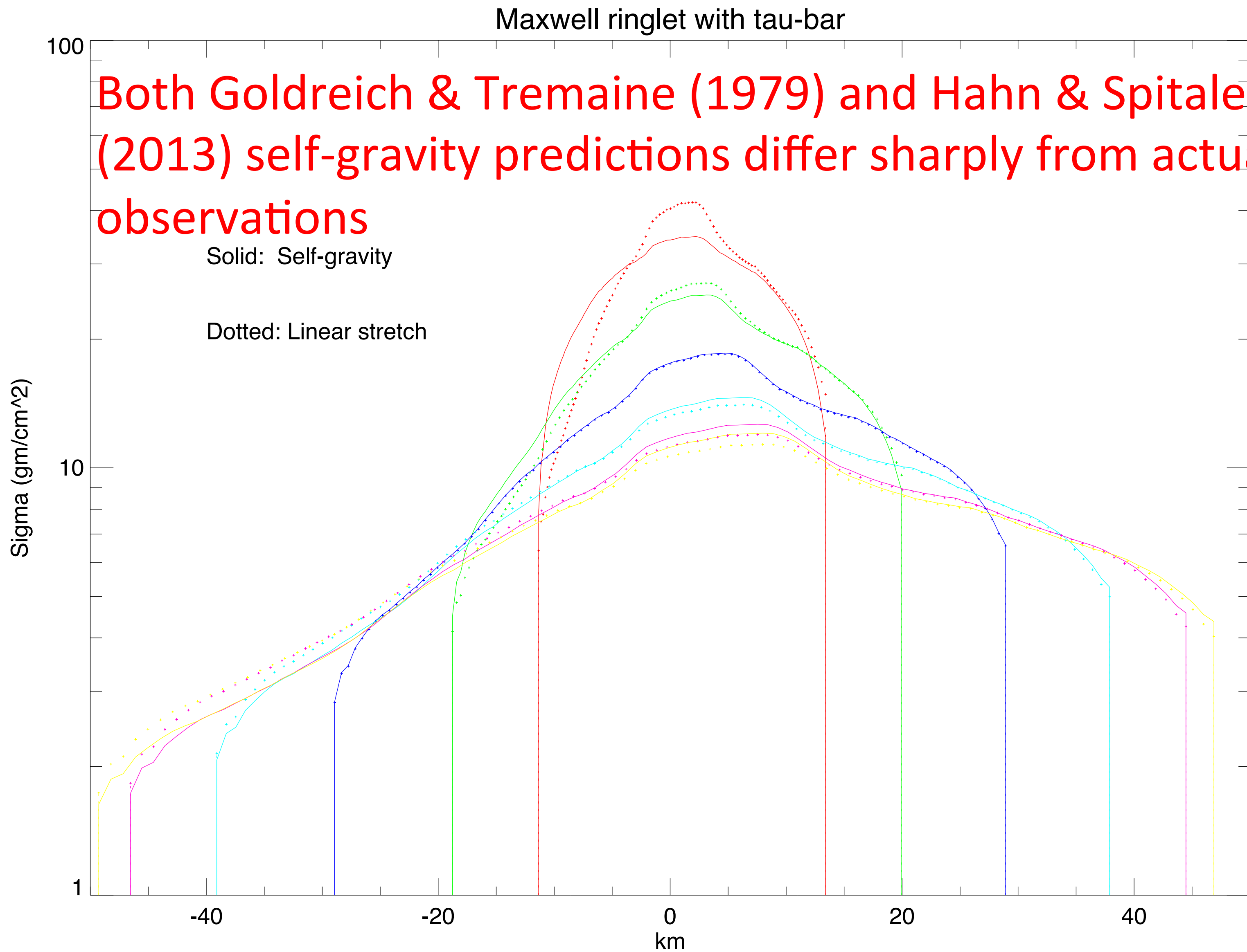
Hahn & Spitale streamline code:

- Successfully models an eccentric ring with an embedded m=2 OLR wave
- Reproduces observed trends in wave shapes
- $M_{\text{"satellite"}} \sim 3 \times 10^{-11} M_{saturn}$

But…

- Self-gravity does not reproduce unperturbed ring profile shape
- Unable to model actual Maxwell Ringlet width variations with true anomaly
- Details of observed radial structure not captured

Both Goldreich & Tremaine (1979) and Hahn & Spitale (2013) self-gravity predictions differ sharply from actual observations



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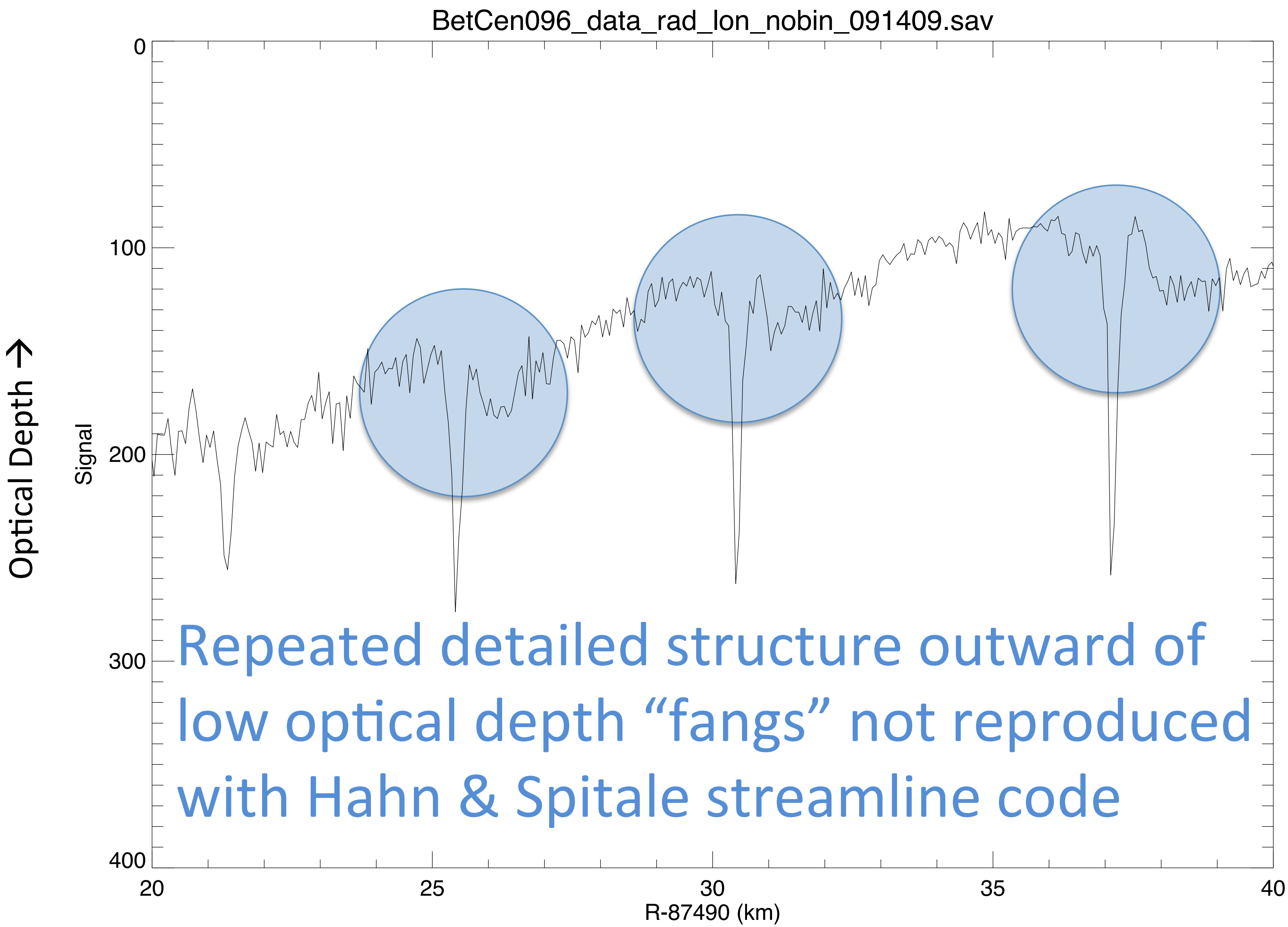

BetCen096_data_rad_lon_nobin_091409.sav
Optical Depth →
Signal
0
100
200
300
400
20
25
30
35
40
R-87490 (km)
Repeated detailed structure outward of low optical depth "fangs" not reproduced with Hahn & Spitale streamline code

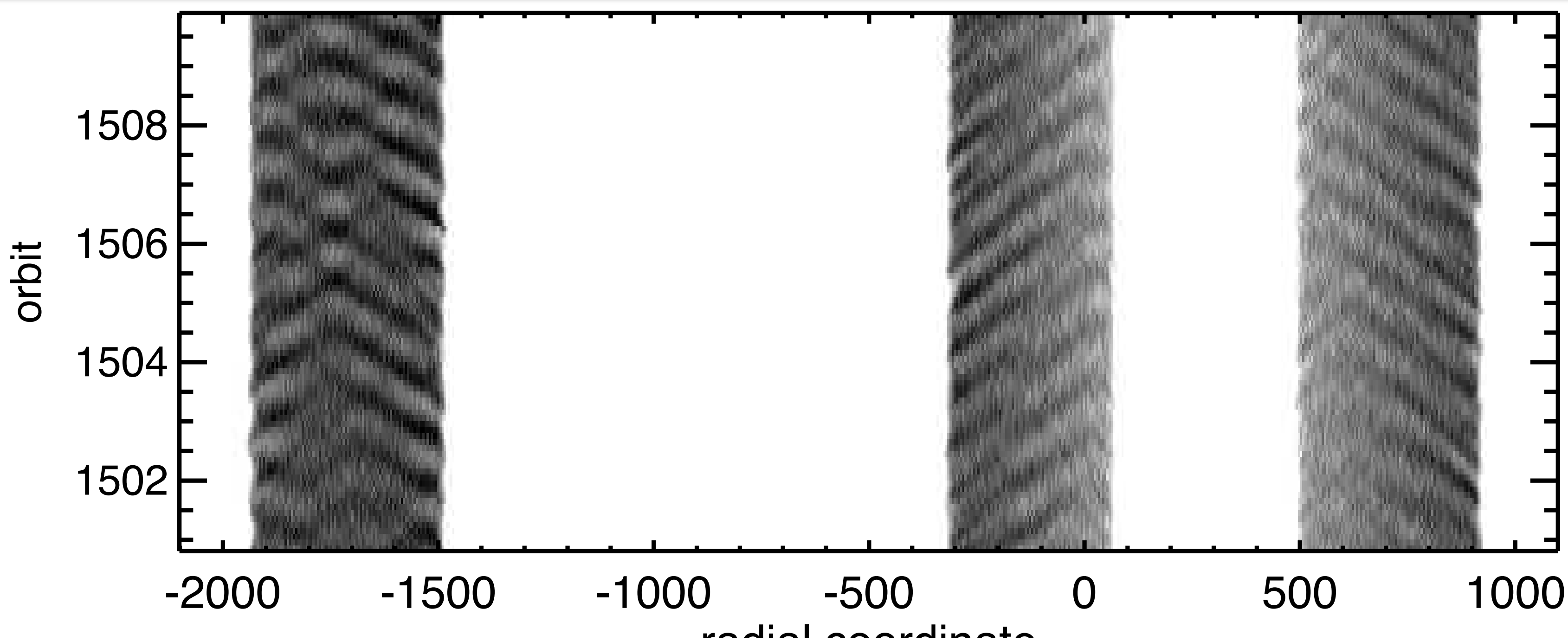
Another dynamical approach (Salo):
Abandon streamline approach and use true N-body integrations with self-gravity, collisions, and periodic boundary conditions

Example: N-body simulation of spontaneous overstable waves with no radial borders

Note vertical structure in lower frames

Oscillations in a narrow ringlet
Viscous instability becomes viscous overstability
Salo and Schmidt (2010)

Note reflection of wave at edges



Modeling the Maxwell Ringlet and wave with traditional N-body periodic boundary condition models is challenging, because:

- strong axisymmetric oscillation required with wavelength >> particle radius
- box size even at maximum compression must be >> wavelength

Hence, box must oscillate in size by a factor of ~5 radially with a period of one orbit, and contain many, many particles

Summary

- Maxwell Ringlet is host to an m=2 OLR wave
- Marley and Porco (1993) predicted m=2 OLR near Maxwell gap at 87,400 km, from Saturn planetary oscillations
- Observed R_{res}= 87,532.8, compared to M&P 86,215+/- 550 km
- Other OLR's are seen in C ring and are associated with Saturn acoustic modes (Hedman & Nicholson 2013, 2014)
- Based on Hahn & Spitale streamline models, the equivalent mass of a satellite driving the observed wave has $M_{\text{"satellite"}} \sim 3 \times 10^{-11}\ M_{saturn}$
- Much of the detailed structure of the wave can be reproduced using N-body streamline models
- However, overall structure does not match standard self-gravity model predictions, and detailed structure near sharp optical depth features in waves still not explained.
- Ongoing N-body simulations may provide better match with observations, but these are computationally challenging