Kronoseismology II: Further searches for Saturn-driven waves in the C Ring

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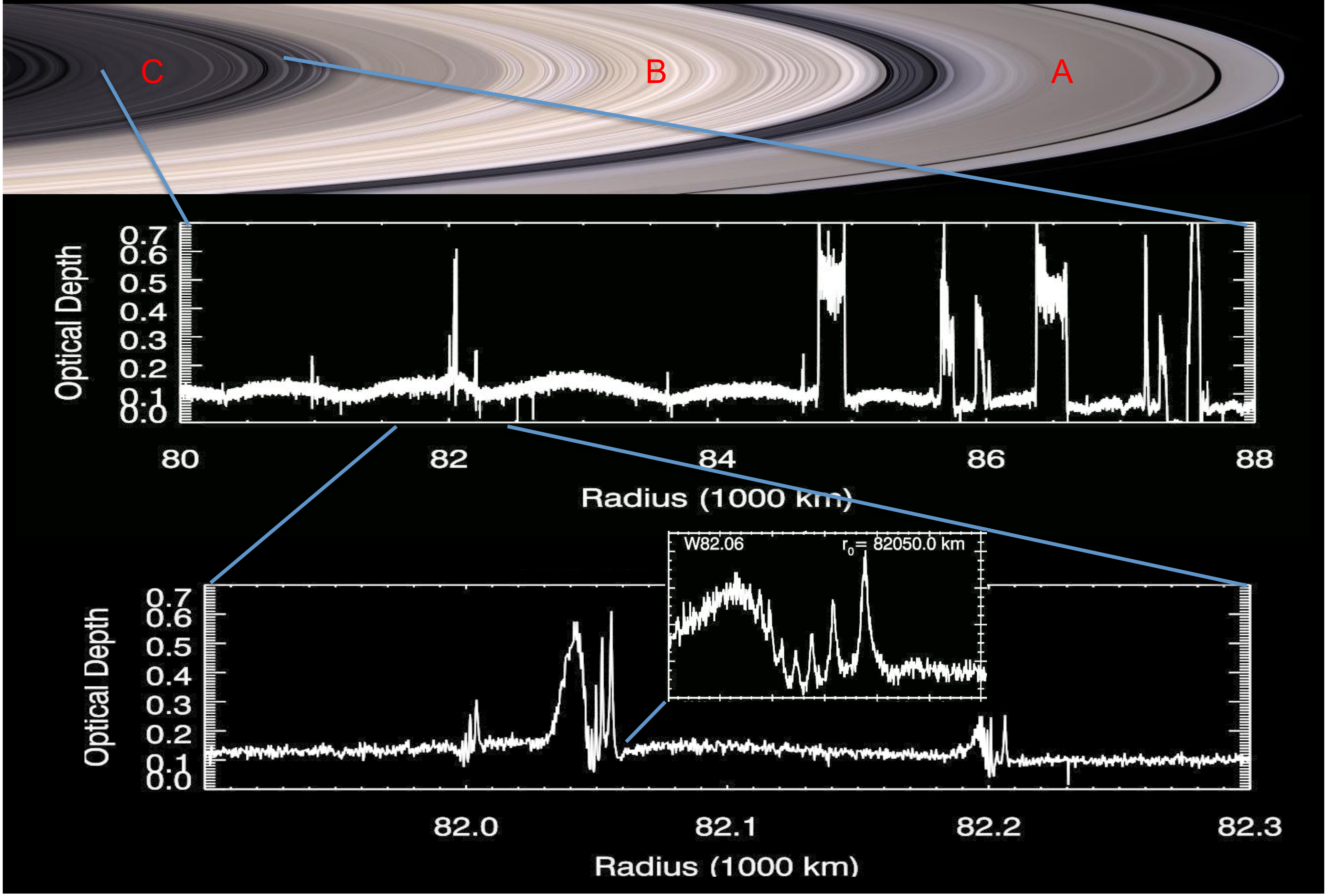
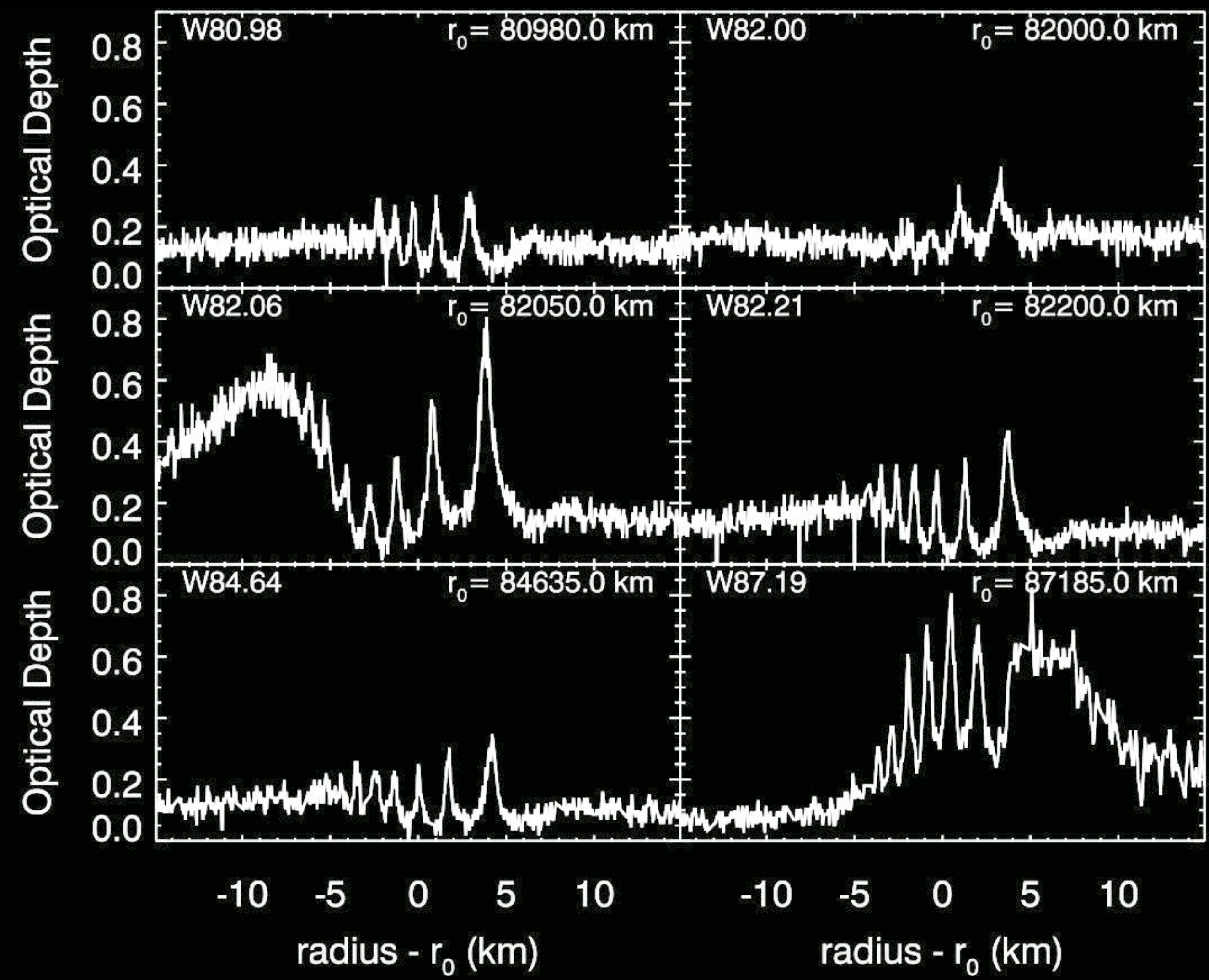
Planetary Rings Workshop, Boulder CO, August 2014

Most density-wavelike patterns in the C ring do not match any known satellite resonances.

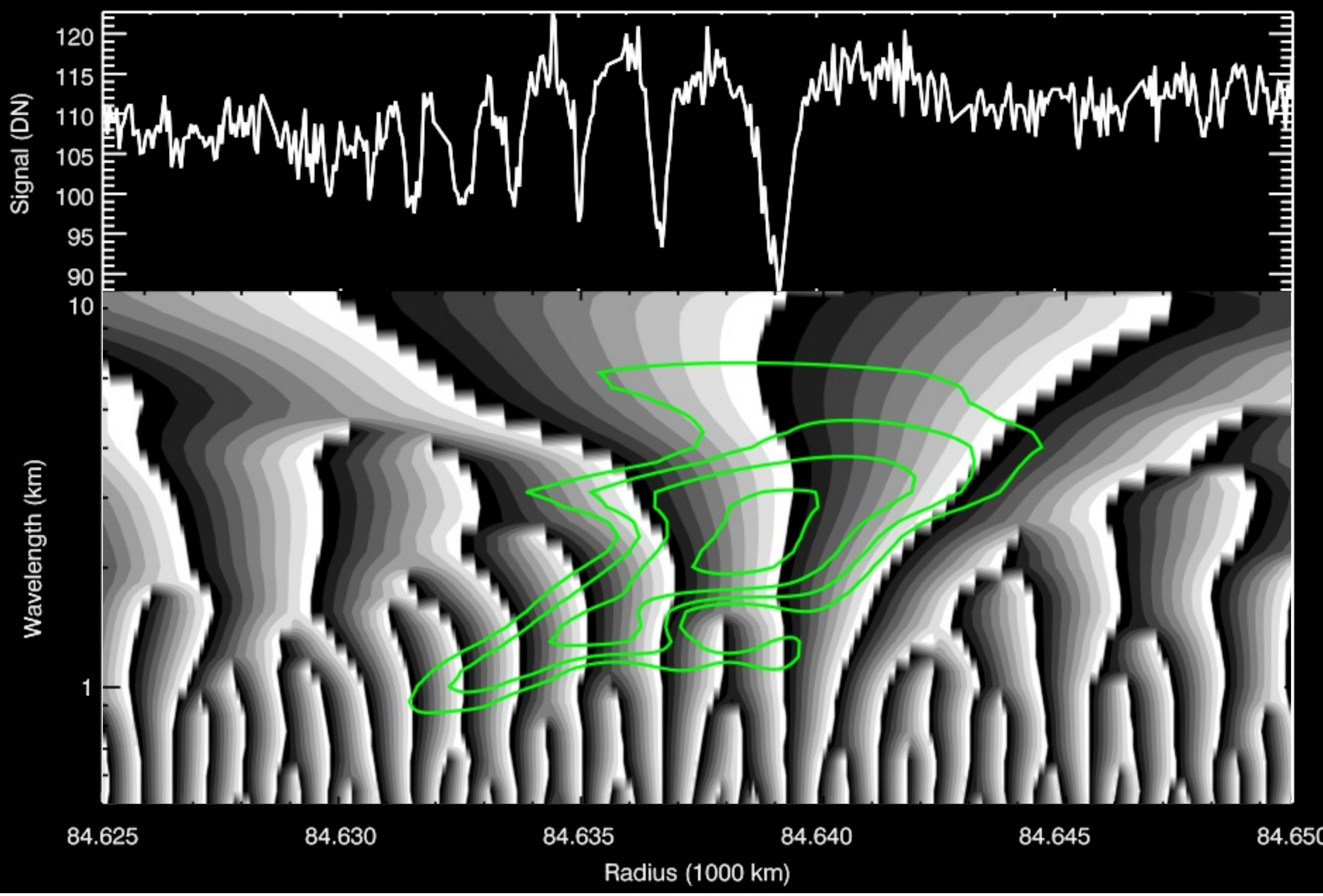


We previously studied 6 of the best-resolved waves in the Cassini-VIMS stellar occultation data:

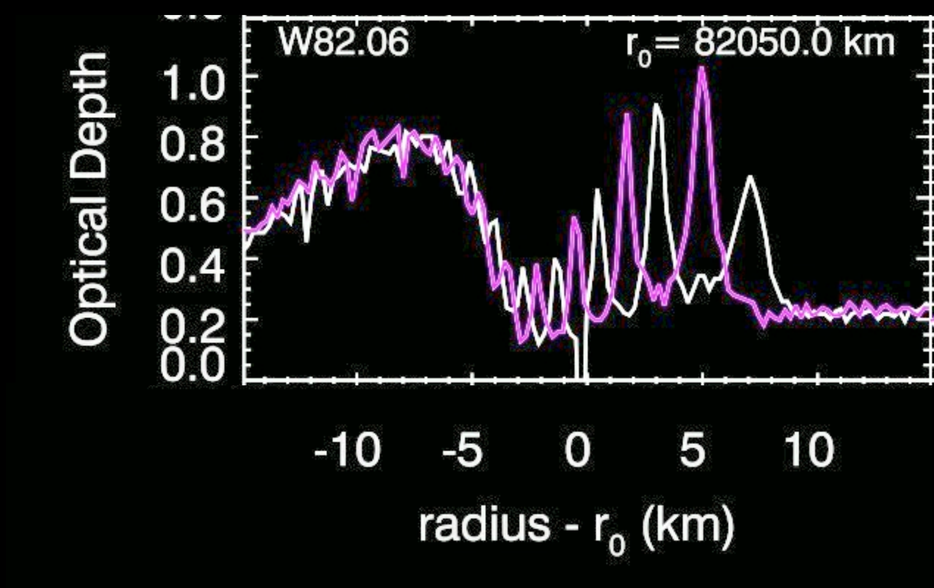


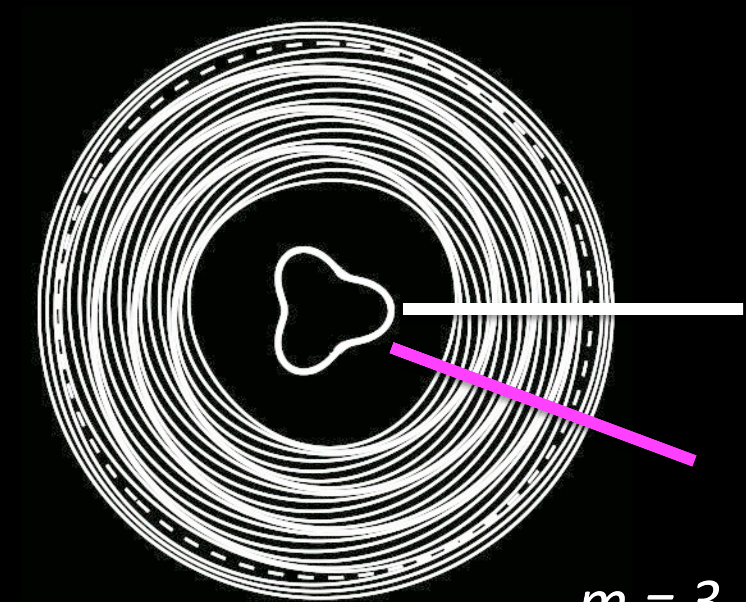
All 6 waves appear to propagate inwards => OLRs driven by Saturn normal modes?

We use wavelet transforms to measure the amplitude and phase of a wave as a function of radius & wavelength.

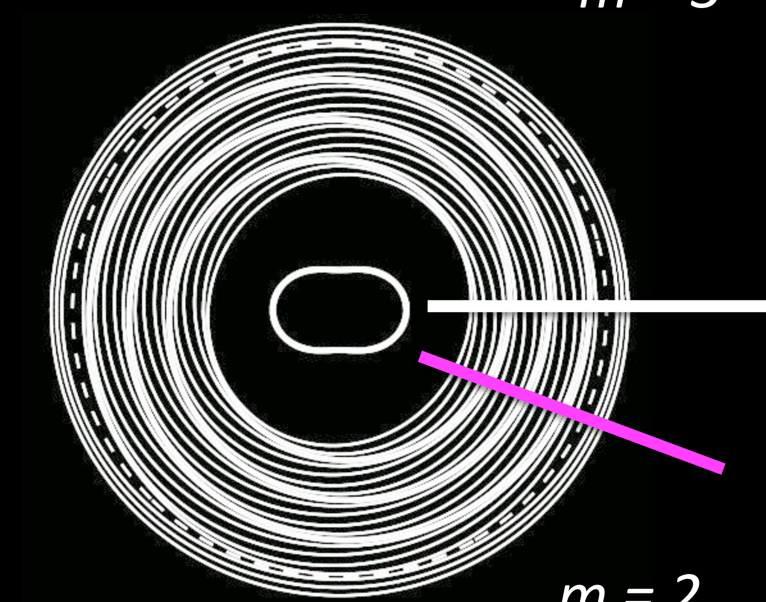


We can determine the m-numbers and pattern speeds of the waves by comparing observations taken at different times and longitudes.





m = 3

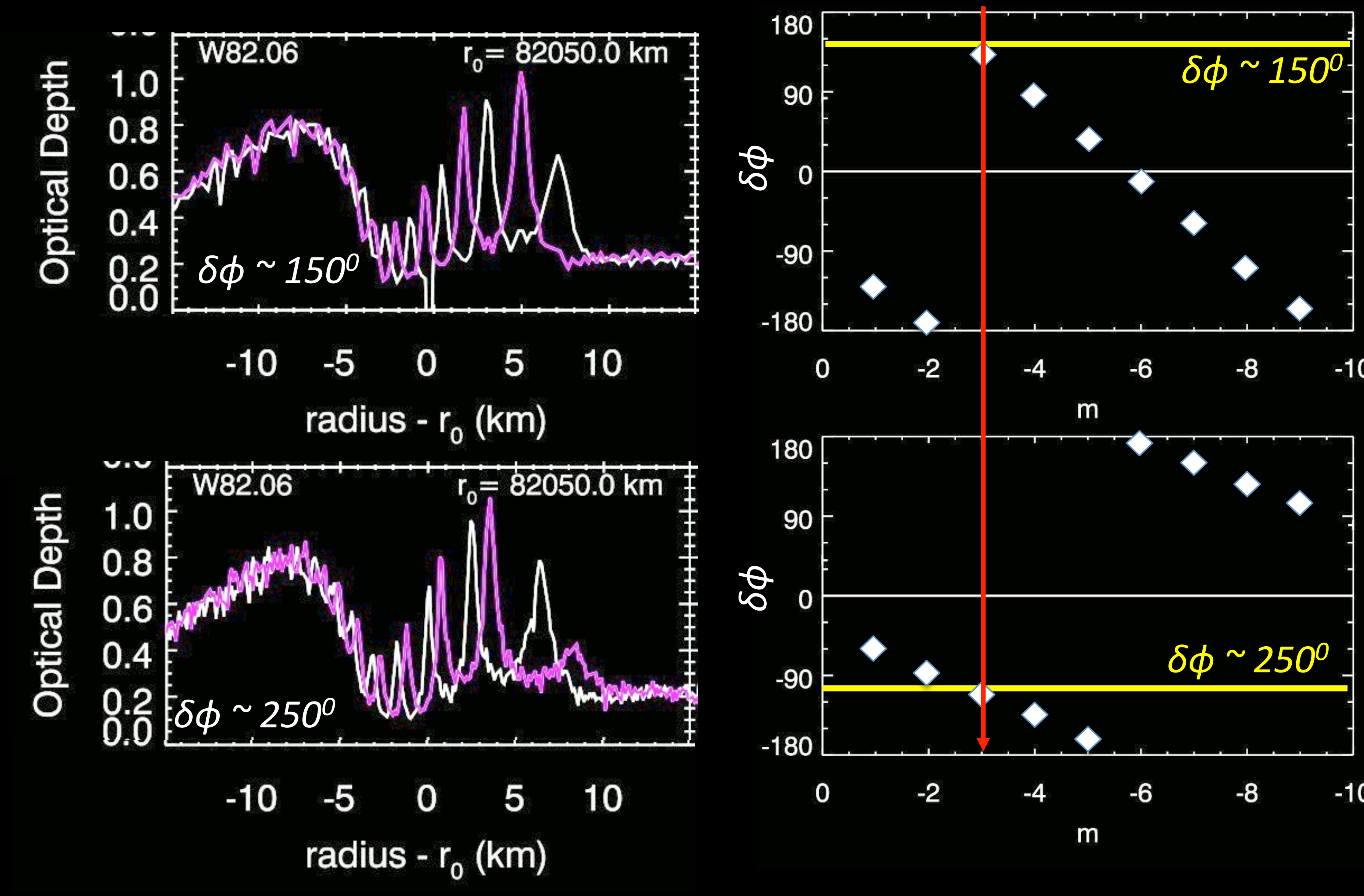


m = 2

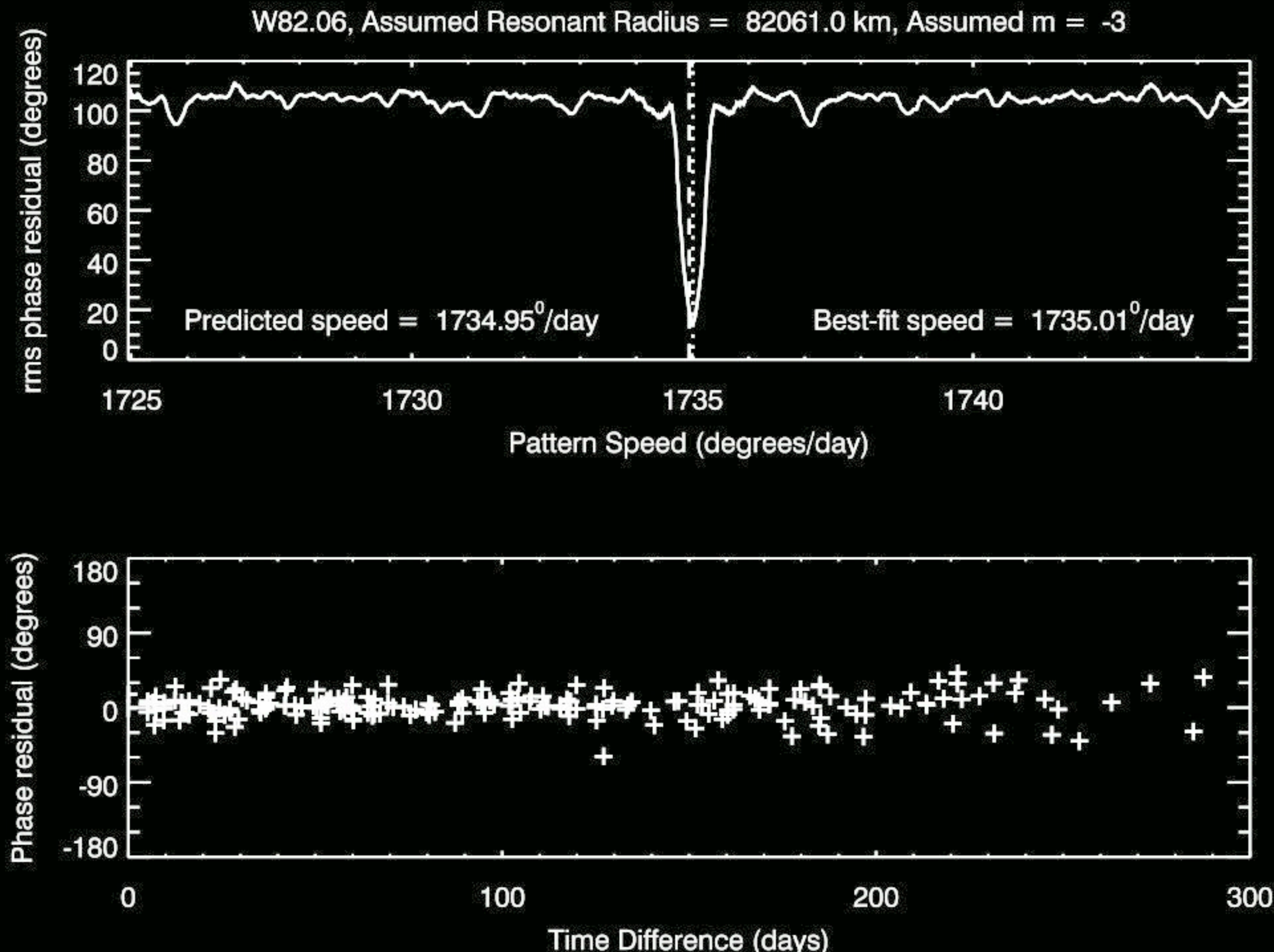
df (predicted) = |m| (dl – W dt)

W = [(m+1) n – dw/dt] / m

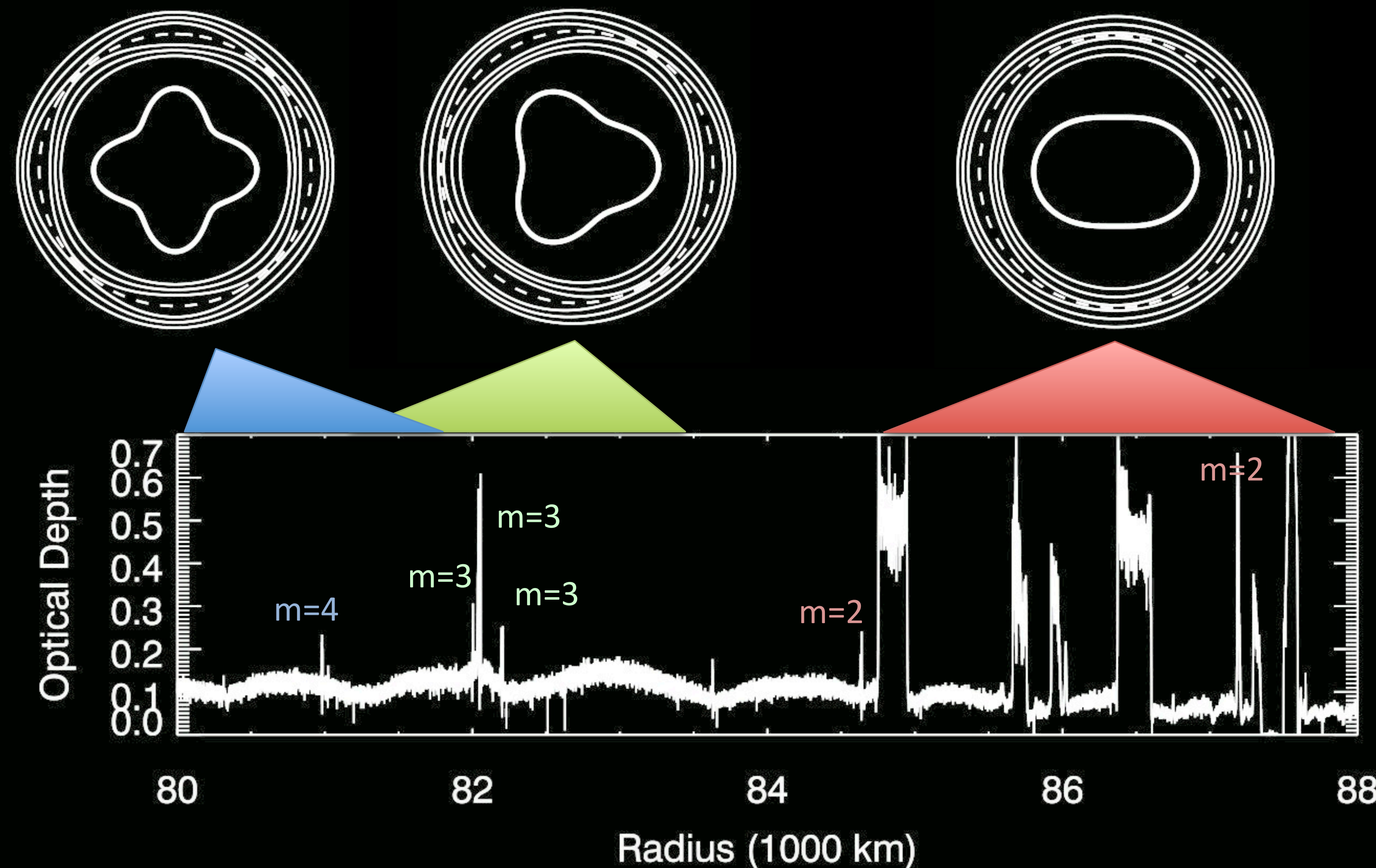
The expected δφ matches the observed value of δφ for the W82.06 wave in two different occultations, for the m=3 mode



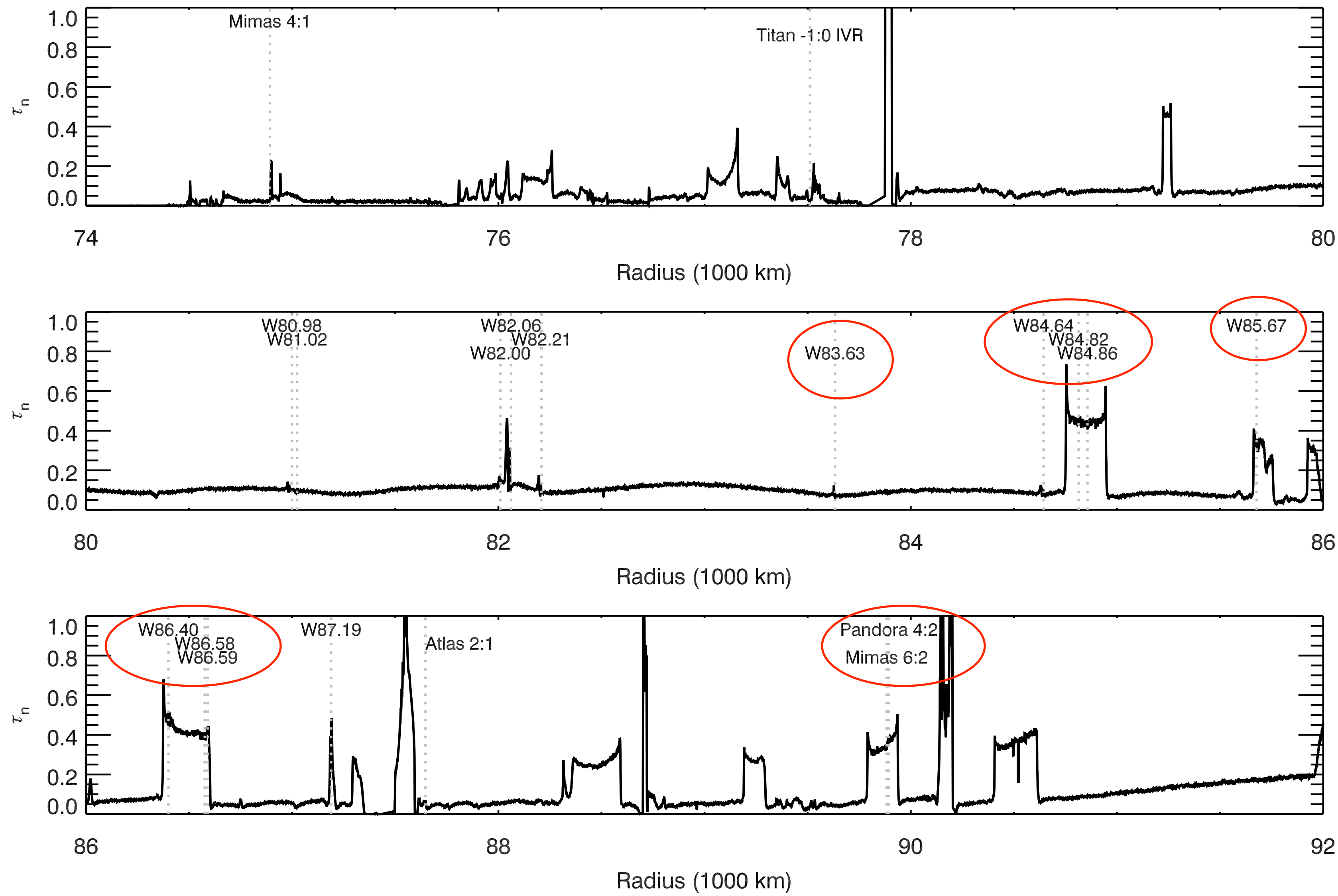
Repeating this analysis for all pairs of occultations <300 days apart, we find a strong m=-3 (OLR) signature for this wave (= Rosen wave f):

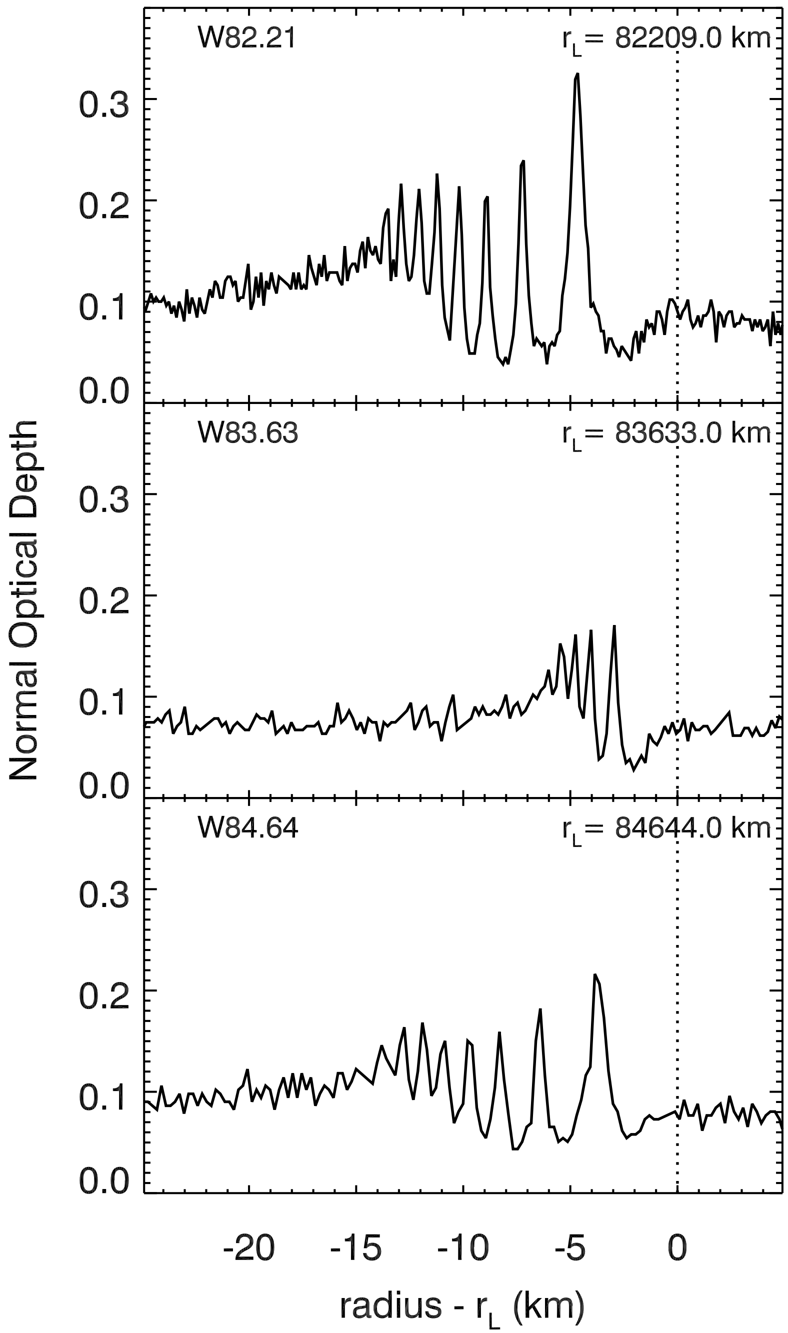


The derived mode-numbers & pattern speeds are consistent with Marley & Porco's (1993) predicted values, but we found multiple waves generated by resonances with the m = 2 and m = 3 modes!

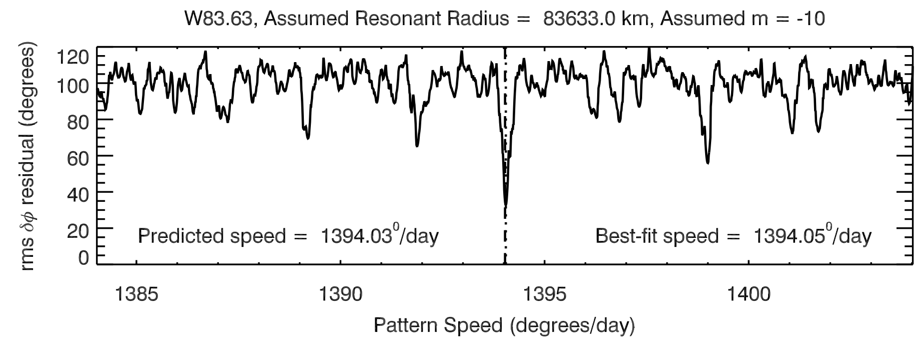


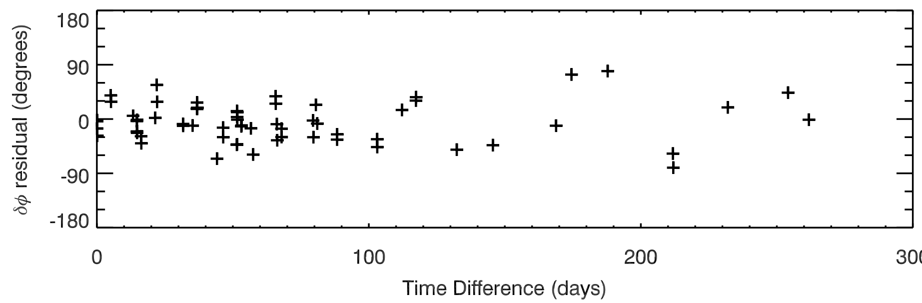
We have now looked at many of the weaker waves in the catalog of Baillie etal (2011), using the same wavelet technique.





The wave at 83.63 kkm fits an f-mode oscillation with m=10.

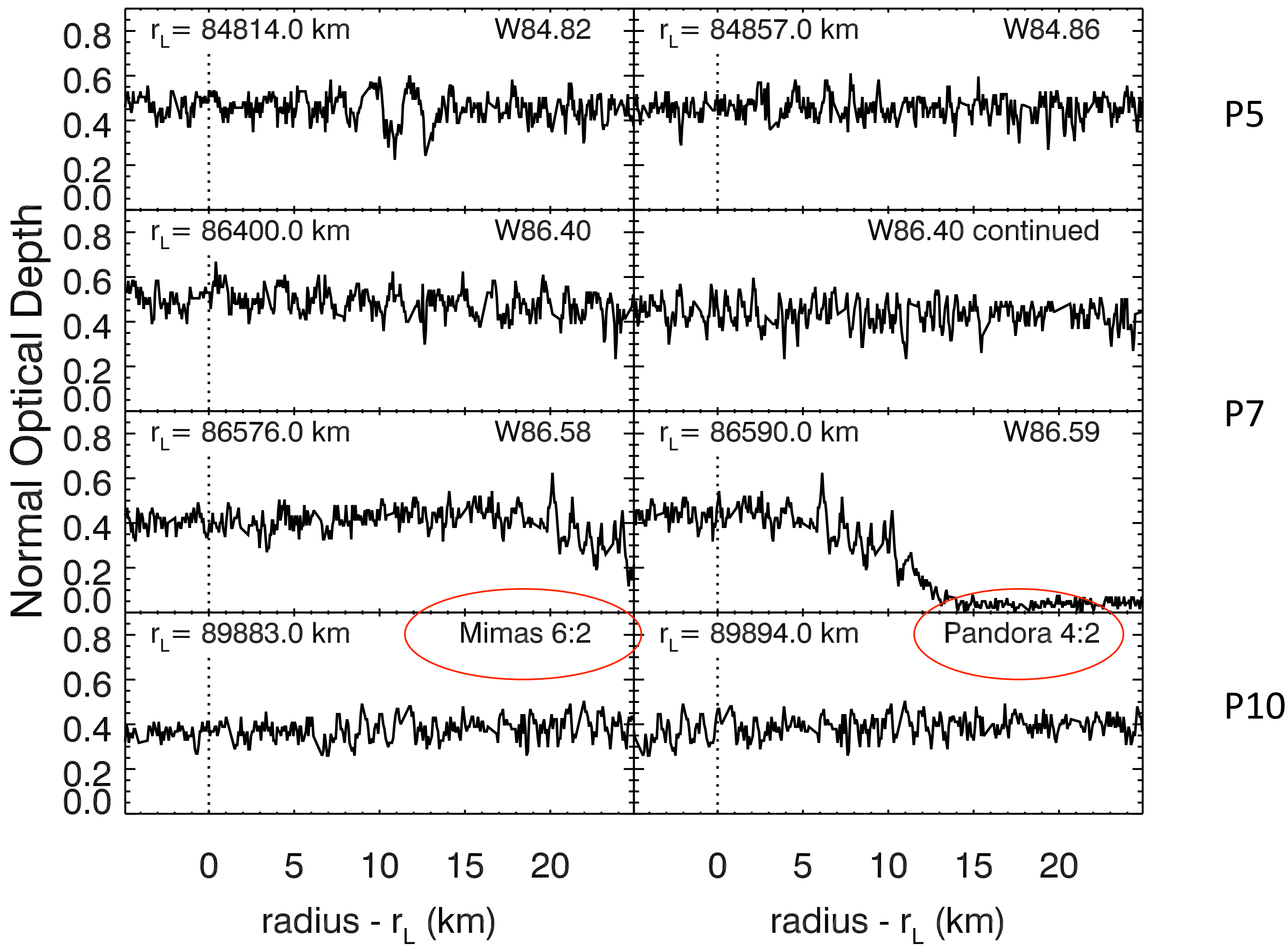




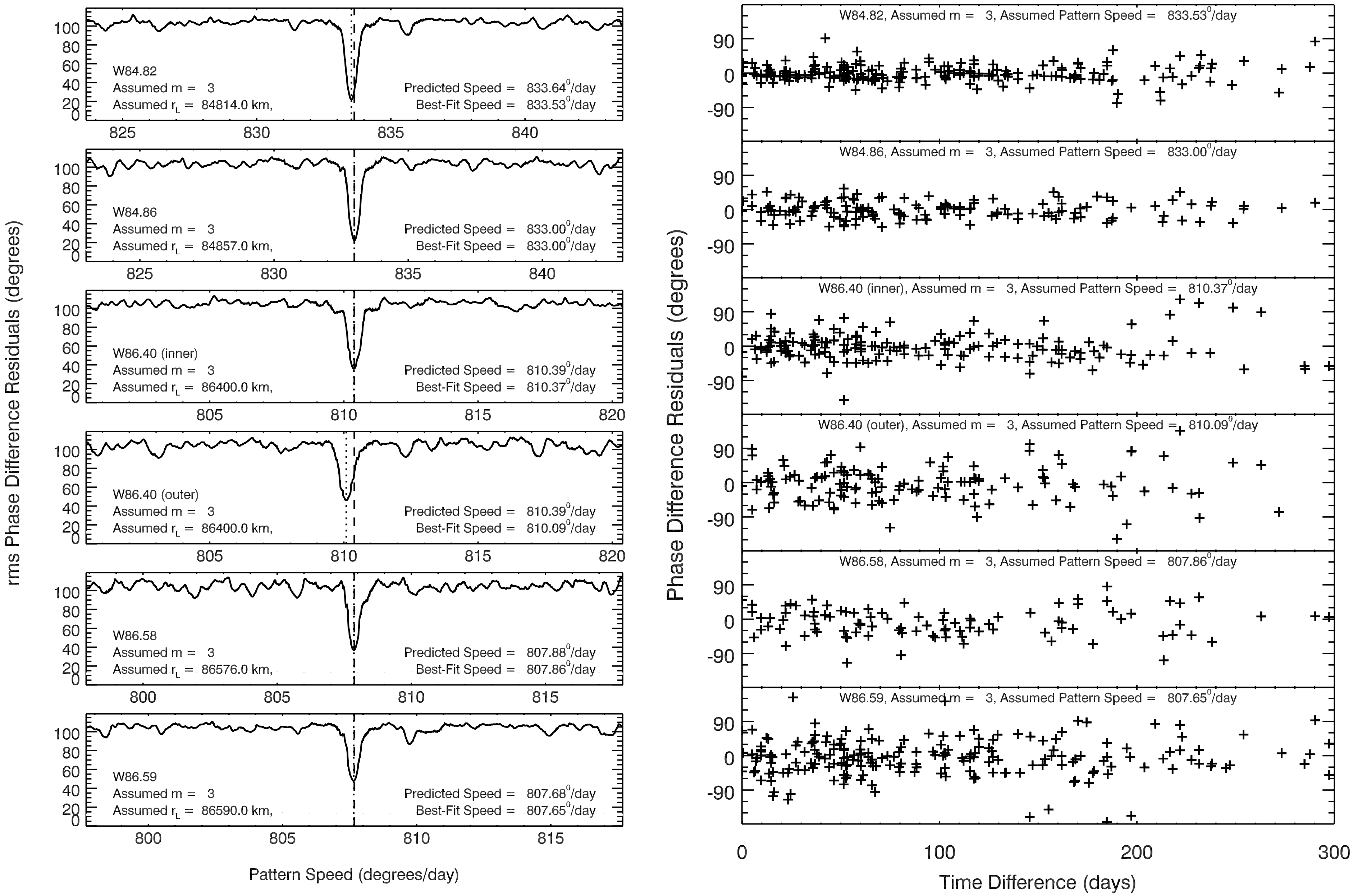
The wave at 81.02 kkm is ambiguous: it fits either m=5 or m=11.

We see no waves for m = 6 thru m = 9

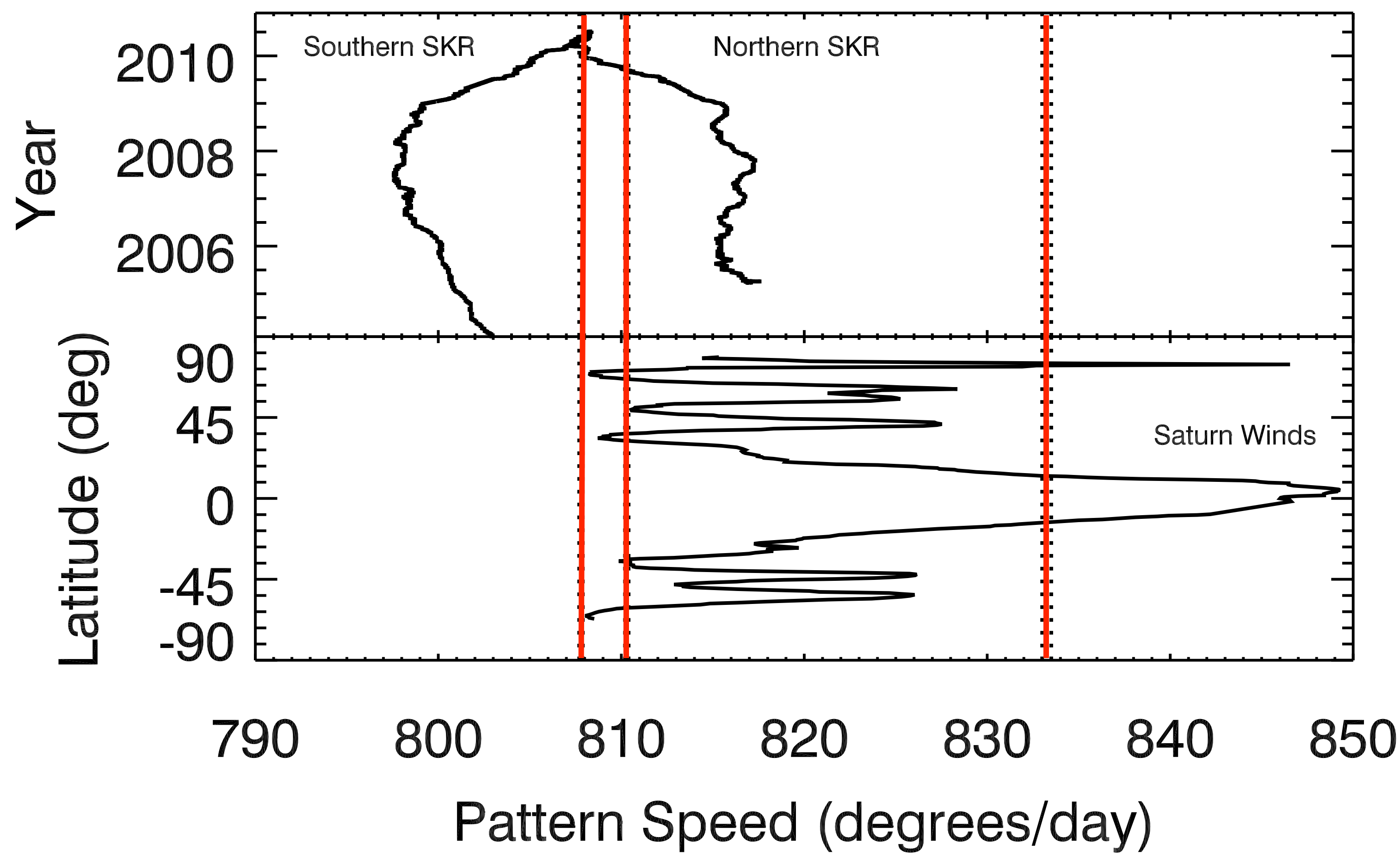
Seven waves are found in plateaux in the outer C ring;
two were identified as satellite waves by Baillie etal.

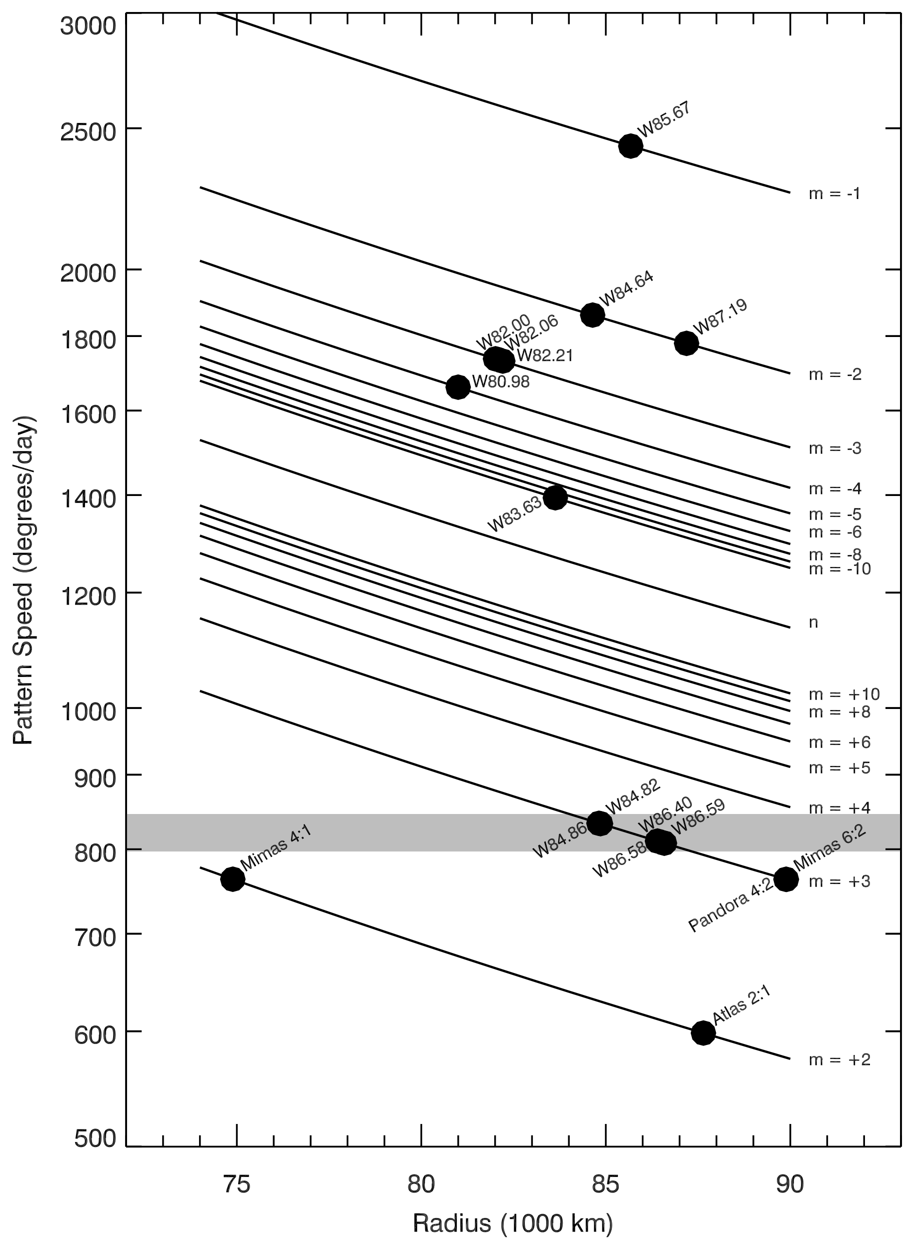


The other 5 waves are all ILRs with m=3:



These 5 waves have pattern speeds which match the range of measured rotation rates for Saturn, from SKR emissions & atmospheric winds ➔ are they driven by internal gravity anomalies?



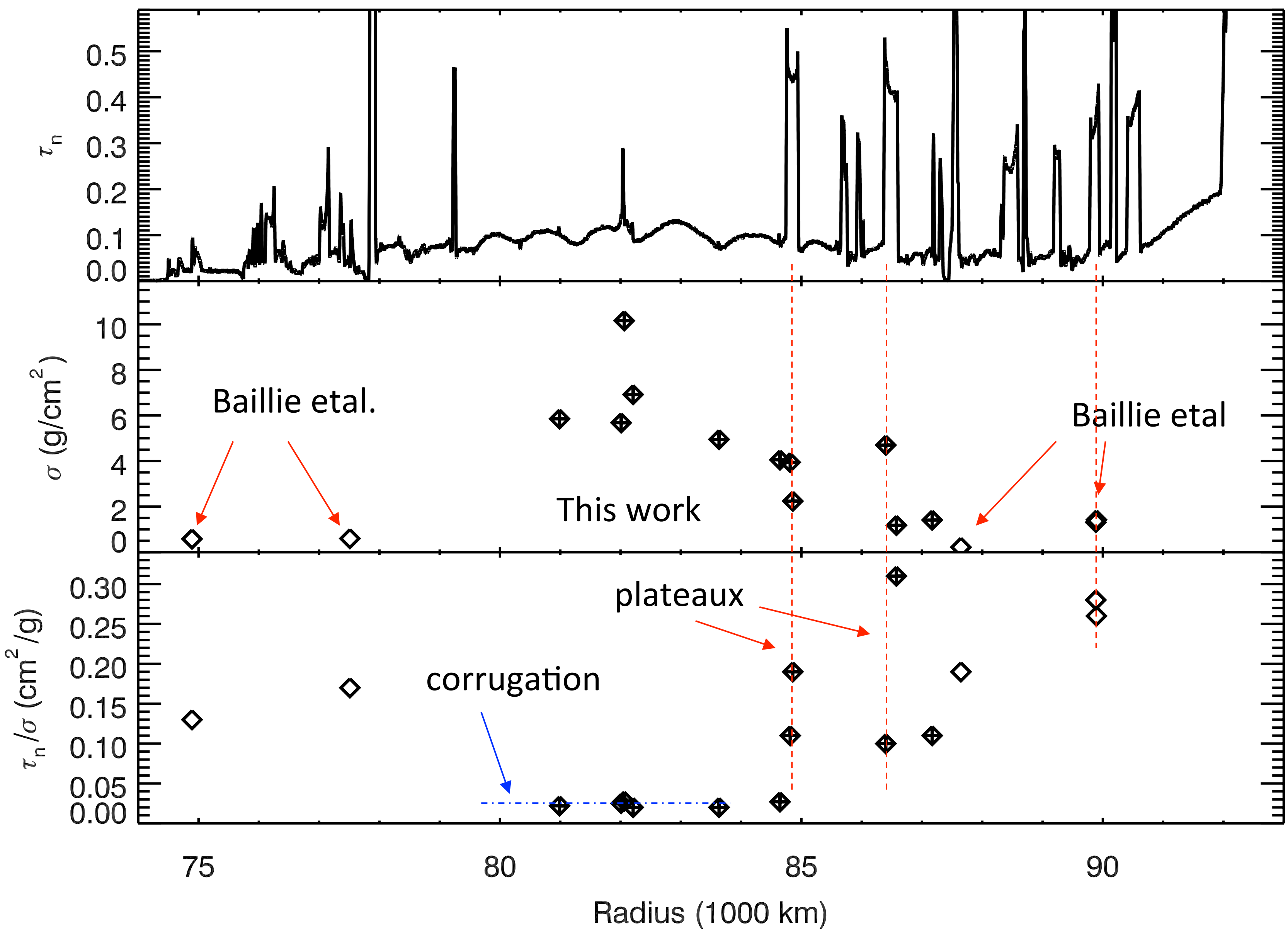


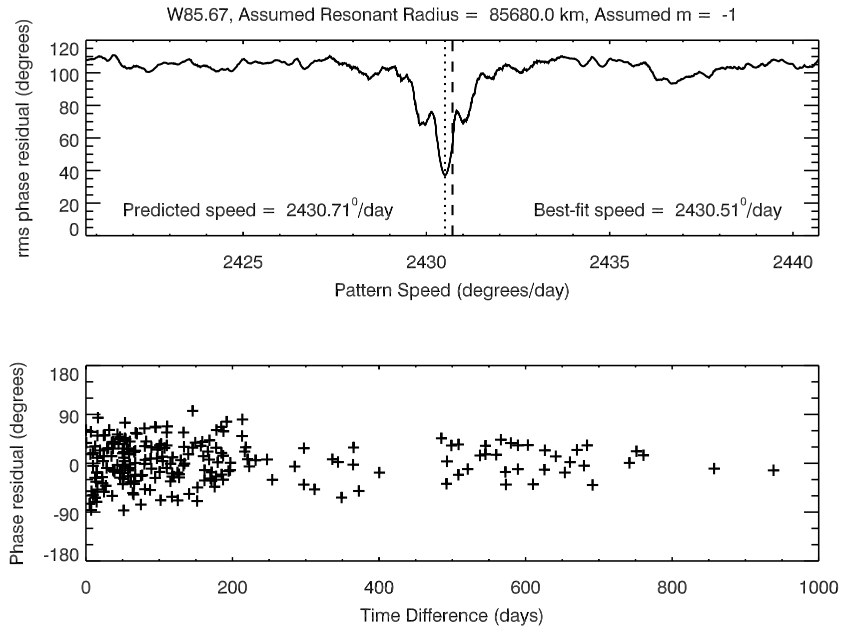
Summary of identified density waves in the C ring by radius, m-value and pattern speed.

OLRs: Saturnian internal f-modes (sectoral modes).

ILRs: external satellites & Saturnian gravity anomalies?

Derived surface mass densities & opacities.

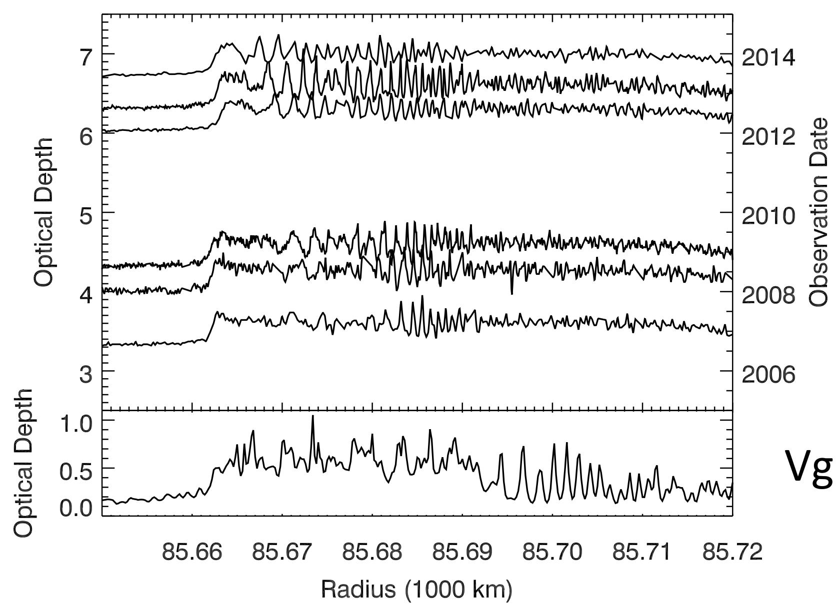




The wave at 85.67 kkm is quite mysterious: it appears to propagate outwards (like an ILR), but its phase fits an OLR-type wave with m=-1 and a very fast pattern speed of 2430 deg/day.

Not only are m=1 sectoral f-modes forbidden, but this wave also seems to be drifting towards Saturn at a rate of 0.8 km/yr over the past 30 yrs…

See Hedman etal (2014 DDA)



Vgr RSS

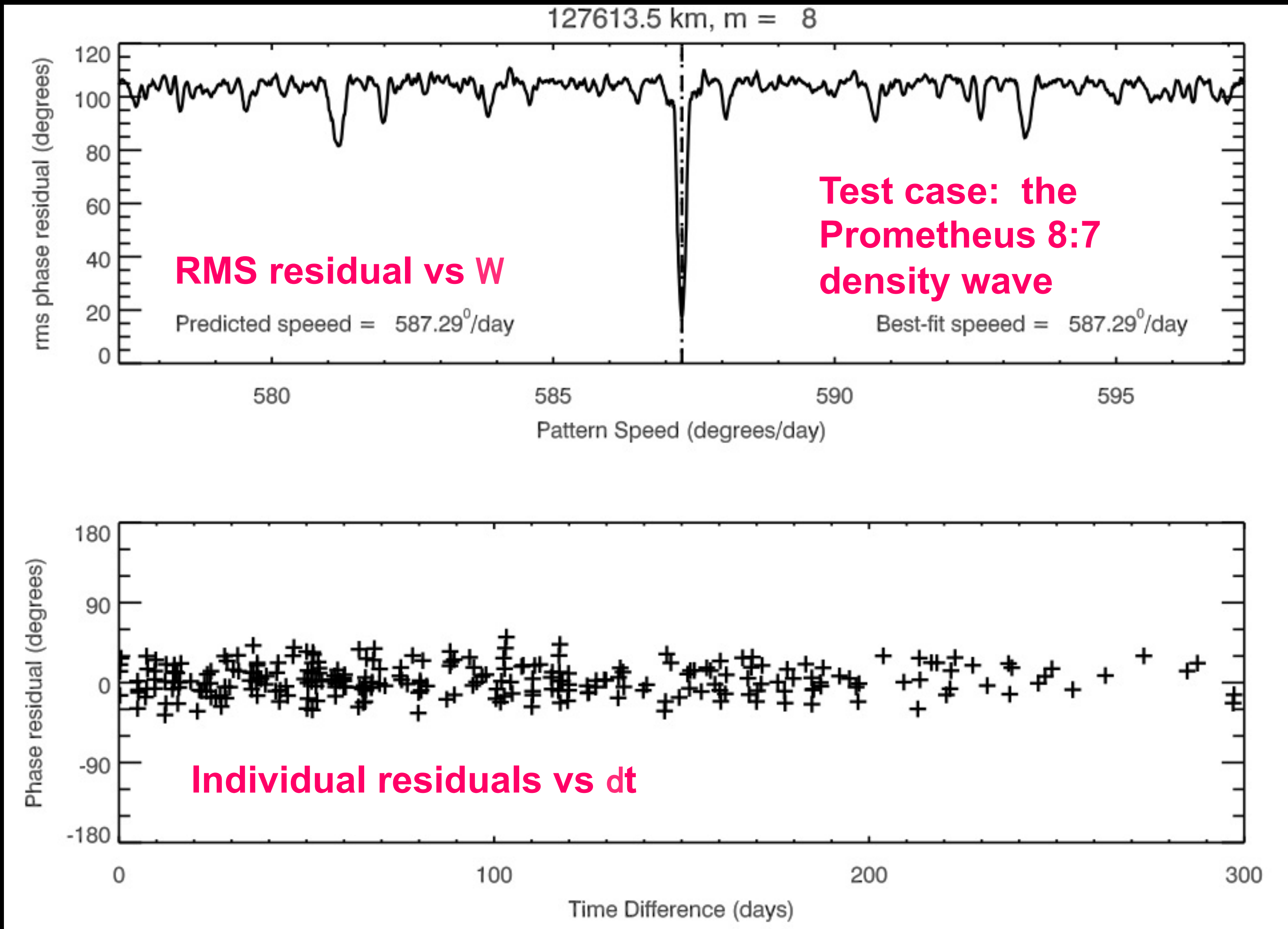
Summary

- Wave W83.63 appears to be due to an m=10 sectoral f-mode.
- Wave W81.02 is either an m=5 or m=10 OLR-type wave.
- There is no sign of waves due to m = 6-9 sectoral f-modes.
- Five waves in P5 & P7 between 84.8 & 86.6 kkm all match m = 3, and appear to be due to gravity anomalies in Saturn.
- Background surface mass densities match previous estimates from satellite DWs and the 1983 impact corrugation.
- The surface mass densities within plateaux are similar to the background C ring, implying much larger opacities (i.e, smaller particle sizes…)
- Wave W85.67 appears to be an m=1 OLR-type wave, but is drifting inwards across plateau P6 at 0.8 km/yr.

Stay Tuned!

Supplemental Material

We can test our phase measurements by calculating the rms O-C phase differences, df – m [dl − W dt] vs W for a known density wave:



Previous calculations had shown that some of these resonances should lie in the C ring.

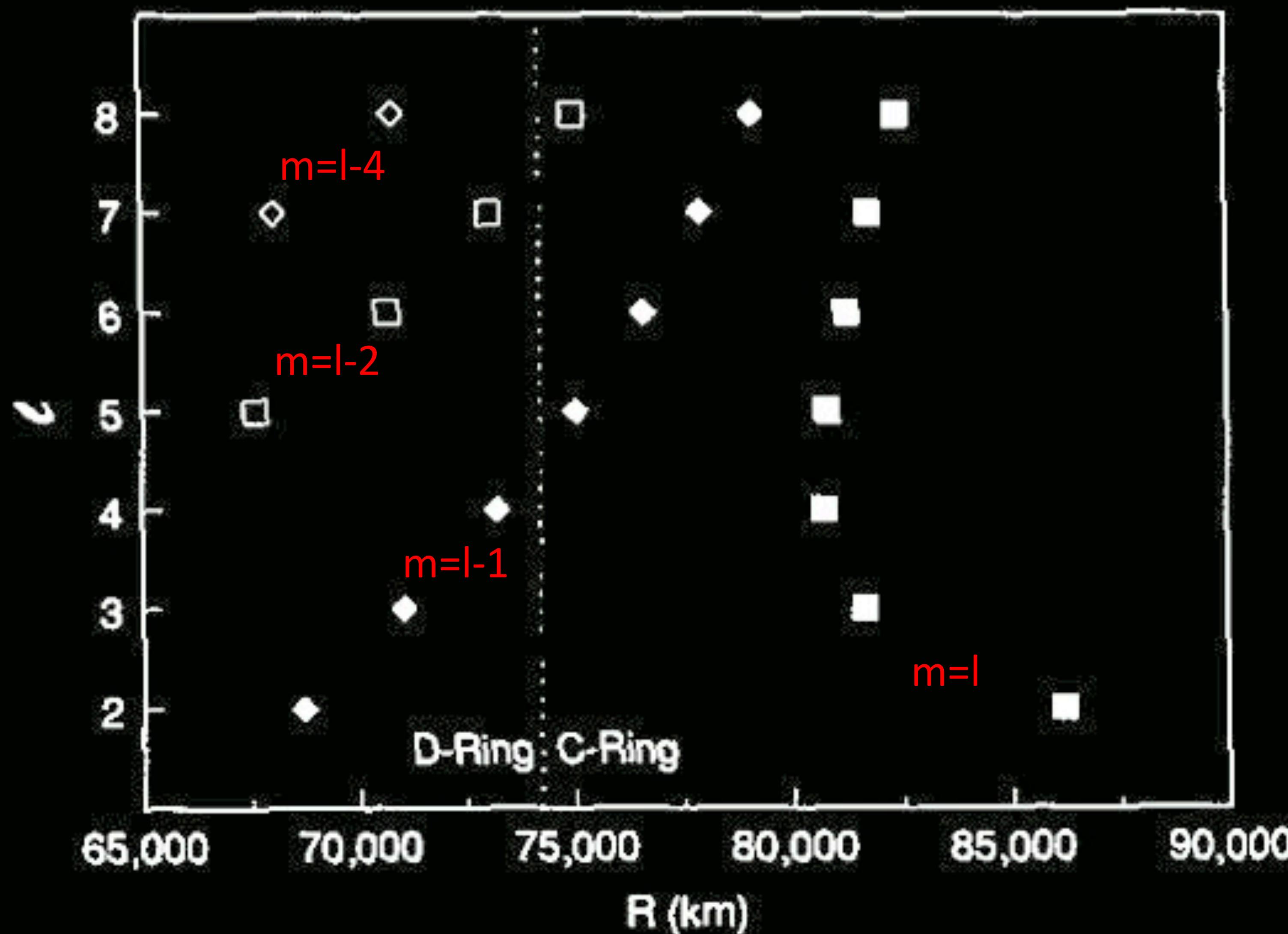
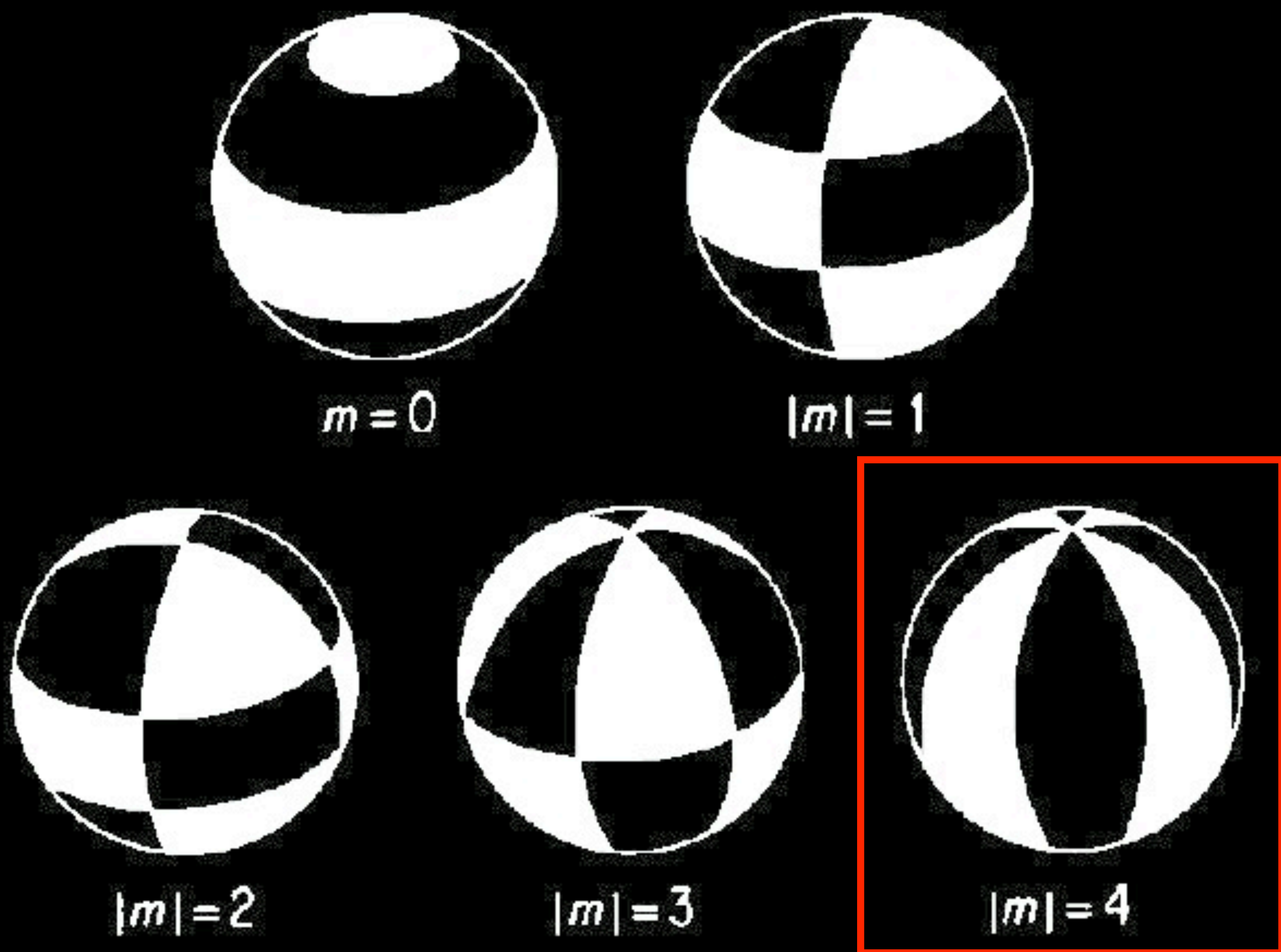


Fig. 4 from Marley and Porco (1983)

The most effective modes for ring torques are the sectoral modes, with m=l. The family of l=4 modes looks like this:



Marley & Porco (1993)

Seismology is the key to understanding the Earth’s interior structure.

Travel times permit the seismic velocity profile to be derived.

The P-wave shadow zone beyond 100 deg demonstrates the existence of a large core.

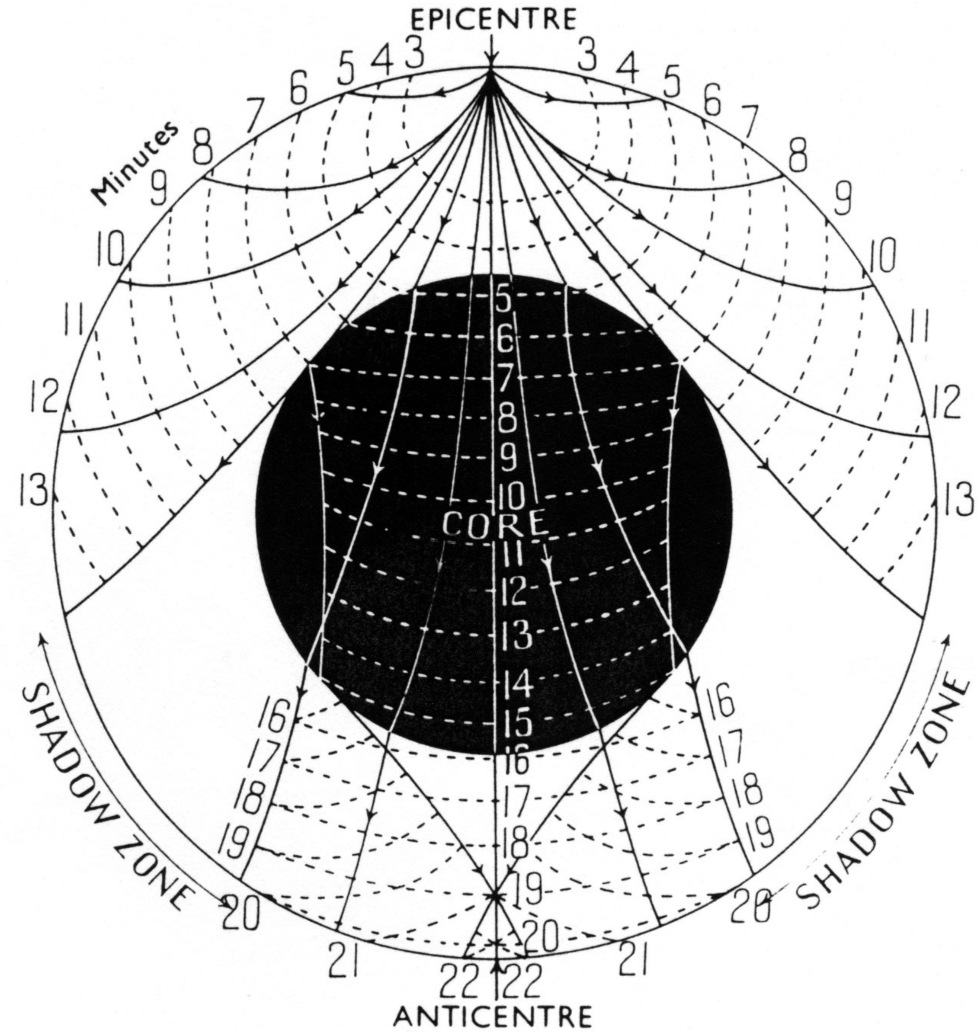
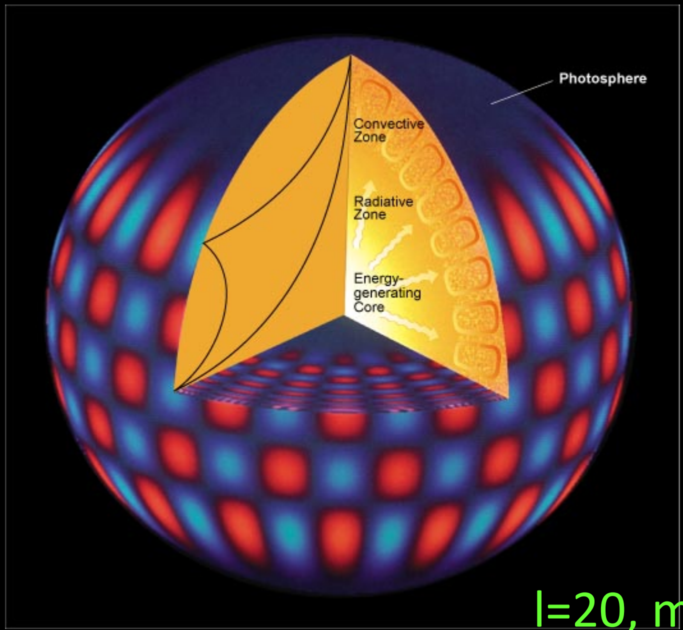
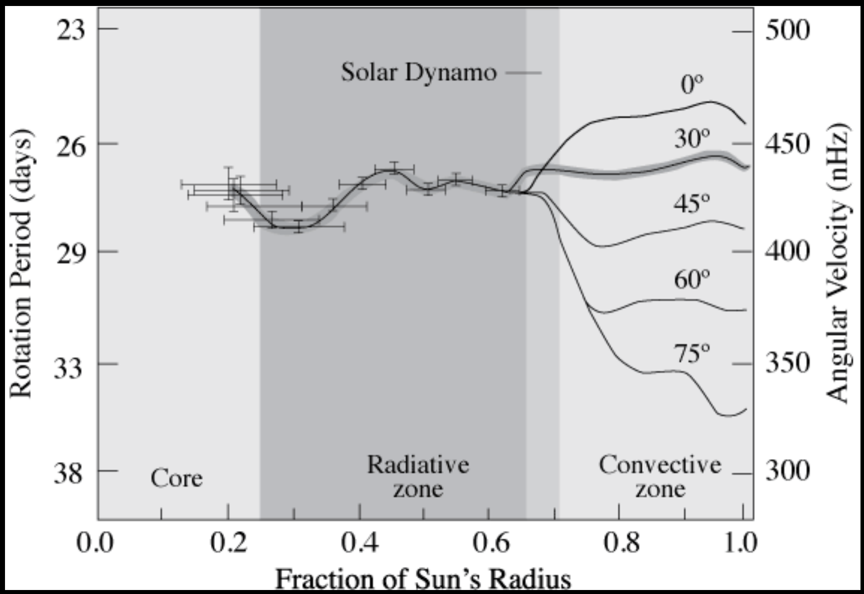


Figure 25.21 Section through the centre of the earth showing the wave paths (firm lines with arrows), wave fronts (dotted lines), and arrival times (in minutes reckoned from the zero time of the shock). Since there is a shadow zone free from P and S waves for each such earthquake, it is inferred that the earth has a core which refracts the deeper waves as shown in the diagram.

Helioseismology and the rotation period of the Sun





Sound waves inside the Sun cause the visible solar disk to vibrate. This radial motion can be described as the superposition of millions of oscillations, including the one shown here for regions pulsing in (*red spots*) and out (*blue spots*). (Courtesy of John W. Harvey, National Optical Astronomy Observatories, except cross sections.)

One result of analyzing these sound waves is the determination of the rotation period of the Sun as a function of latitude and depth. It varies within the convective zone of the Sun, increasing with latitude, but is relatively constant in the radiative zone at about 28 days. The resulting shear in the transition region may generate the solar dynamo, the cause of the Sun's magnetism.