# AM CVn Stars (incl. KIC4547333) and the Two-Source Model for Positive Superhumps

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# Collaborators

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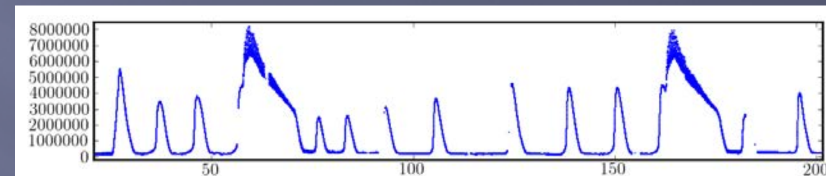
- Florida Tech Undergraduates: Pablo Prado, Brian Gosalvaz, John Robertson, & Victor Calderon

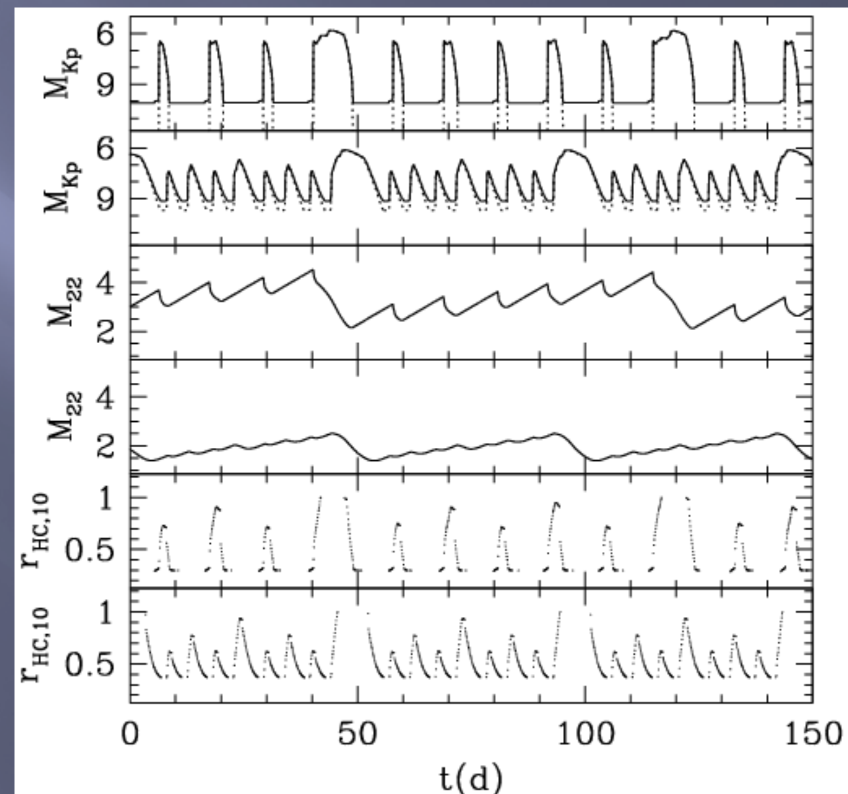
# Outline

- Outbursts & Superoutbursts
- Superhumps: Positive, Negative, and the two sources of flux modulation
- Kepler Observations of non-AM CVn Cataclysmic Variables
- AM CVn, HP Lib, & KIC 5457333 Lightcurves and Interpretation

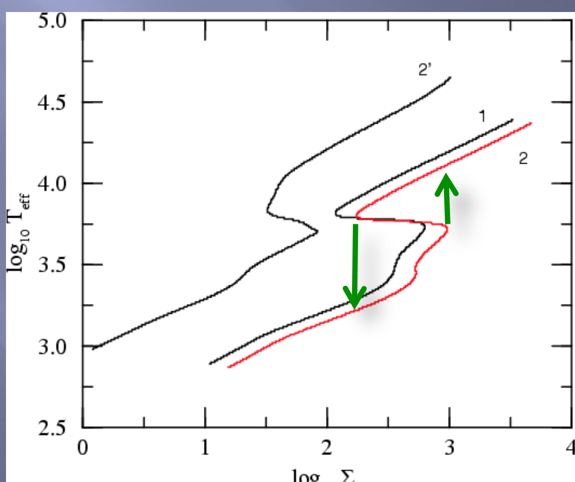
# Thermal-Tidal Instability Model

- Outburst light curves can be modeled using the Thermal-Tidal Instability Model
- Note (panel 3) that total disk mass increases between superoutbursts, and ~1/2 disk mass lost during superoutburst (Kepler data indirectly confirm this)



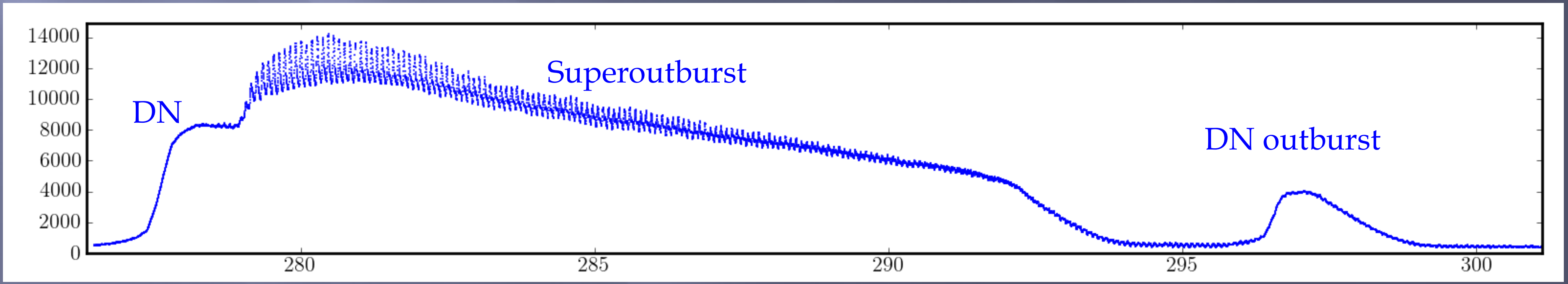




(Cannizzo et al. 2010, ApJ, 725, 1393)

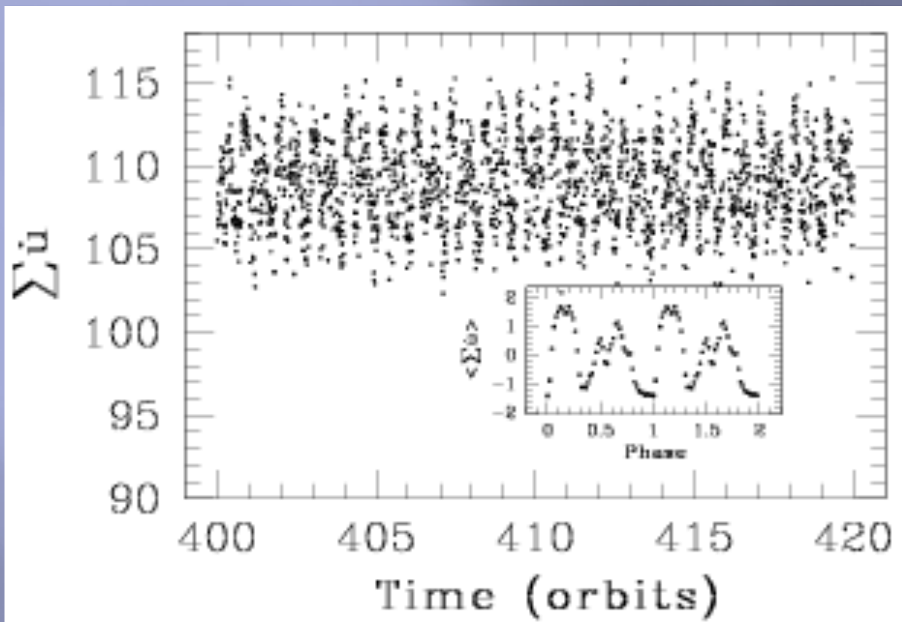


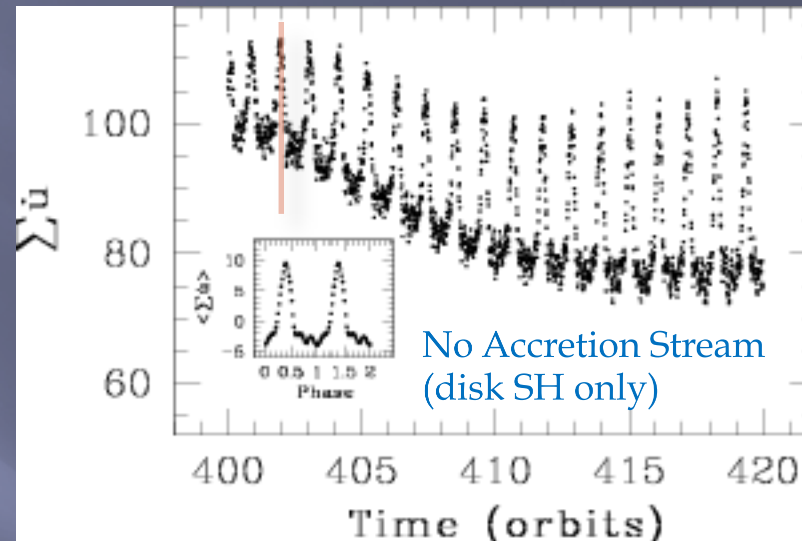
# Superoutbursts and Positive Superhumps

- Each DN outburst expands the outer disk somewhat (conservation of angular momentum)
- If system mass ratio $q \equiv M_2/M_1 < 0.35$ then 3:1 corotation resonance is inside Roche lobe
- Build up enough mass at 3:1 resonance, and a "***positive superhump***" oscillation can be excited
  - Period $P_+$ a few percent in excess of $P_{orb}$ as disk precesses in the prograde direction
  - Superhump period excess $\epsilon_+ \equiv \frac{P_+ - P_{orb}}{P_{orb}}$ from (1) dissipation in the flexing disk itself, and (2) from accretion stream impacting at varying depths in the potential well of the primary ($\rightarrow$ ***the two-source model for positive superhumps***)
  - Flexing disk increases effective viscosity, dM/dt, and $L_{sys}$ $\Rightarrow$ ***Superoutburst***

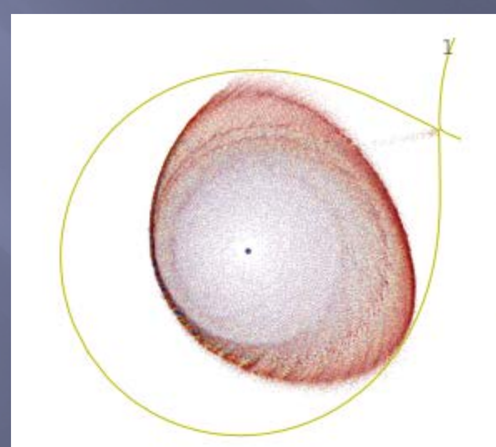


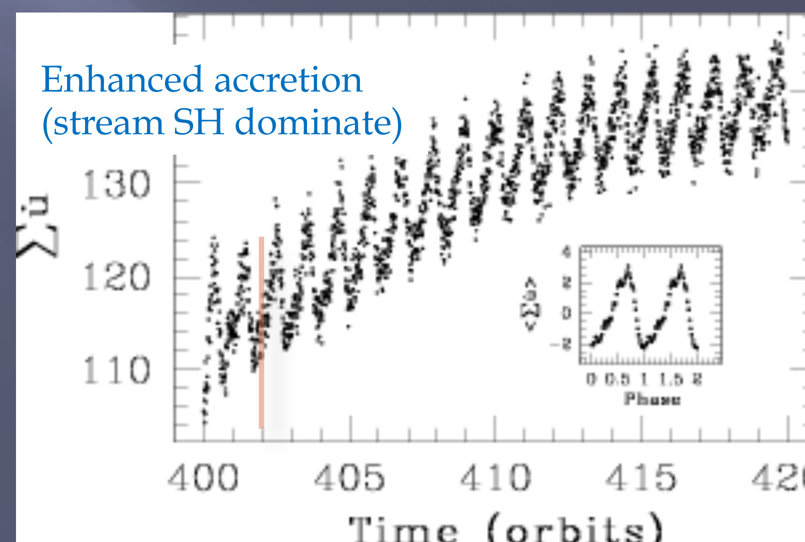
# SPH Simulations of Disk and Stream (late) Positive Superhumps




SPH model results
q = 0.25, 100,000 particles



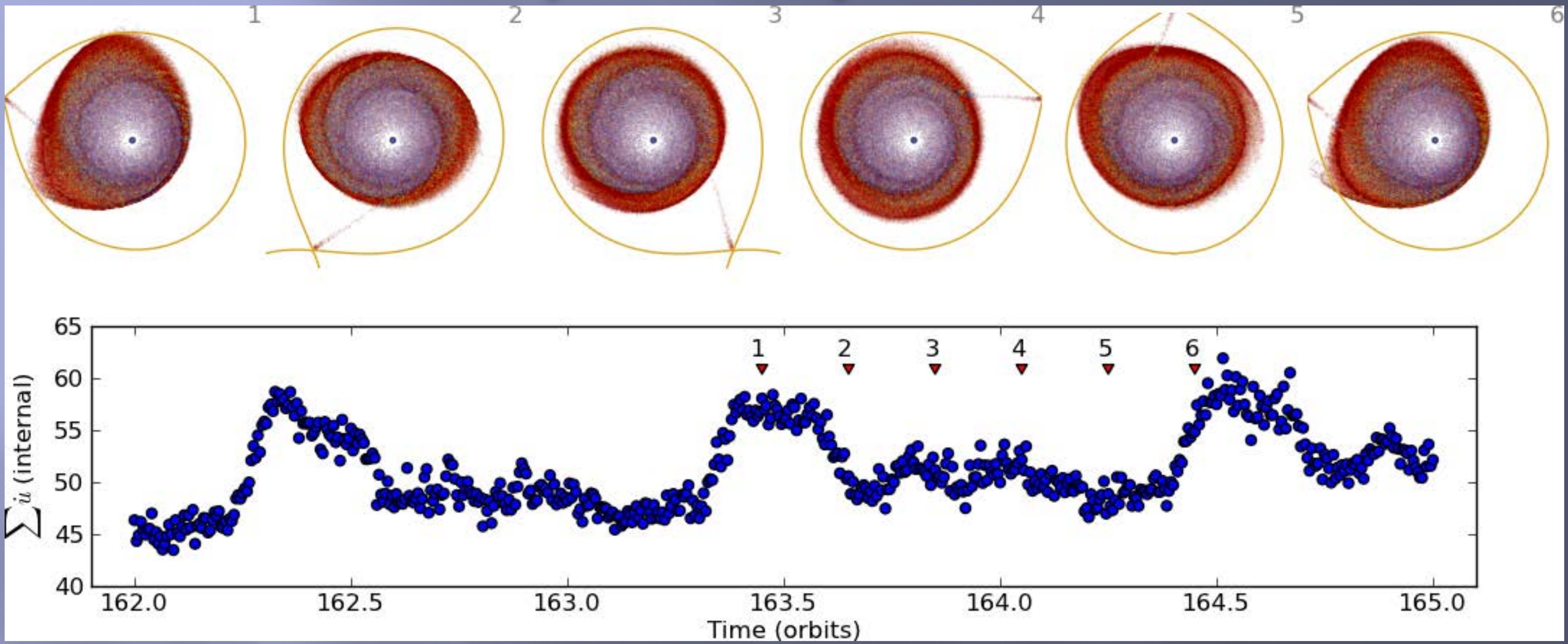



(Wood et al. 2011)

# Negative Superhumps

- Some systems display periods slightly shorter than the orbital period, the period excess defined above is negative, so these became known as Negative Superhumps
- Physical Origin of Negative superhumps
  - A disk tilted out of the orbital plane will precess in the retrograde direction
  - The accretion stream impact point will only hit the rim of the disk 2x per orbit
  - At all other phases, the impact point will be deeper in the potential well – more specific KE, so brighter

# Positive Superhump SPH Simulation



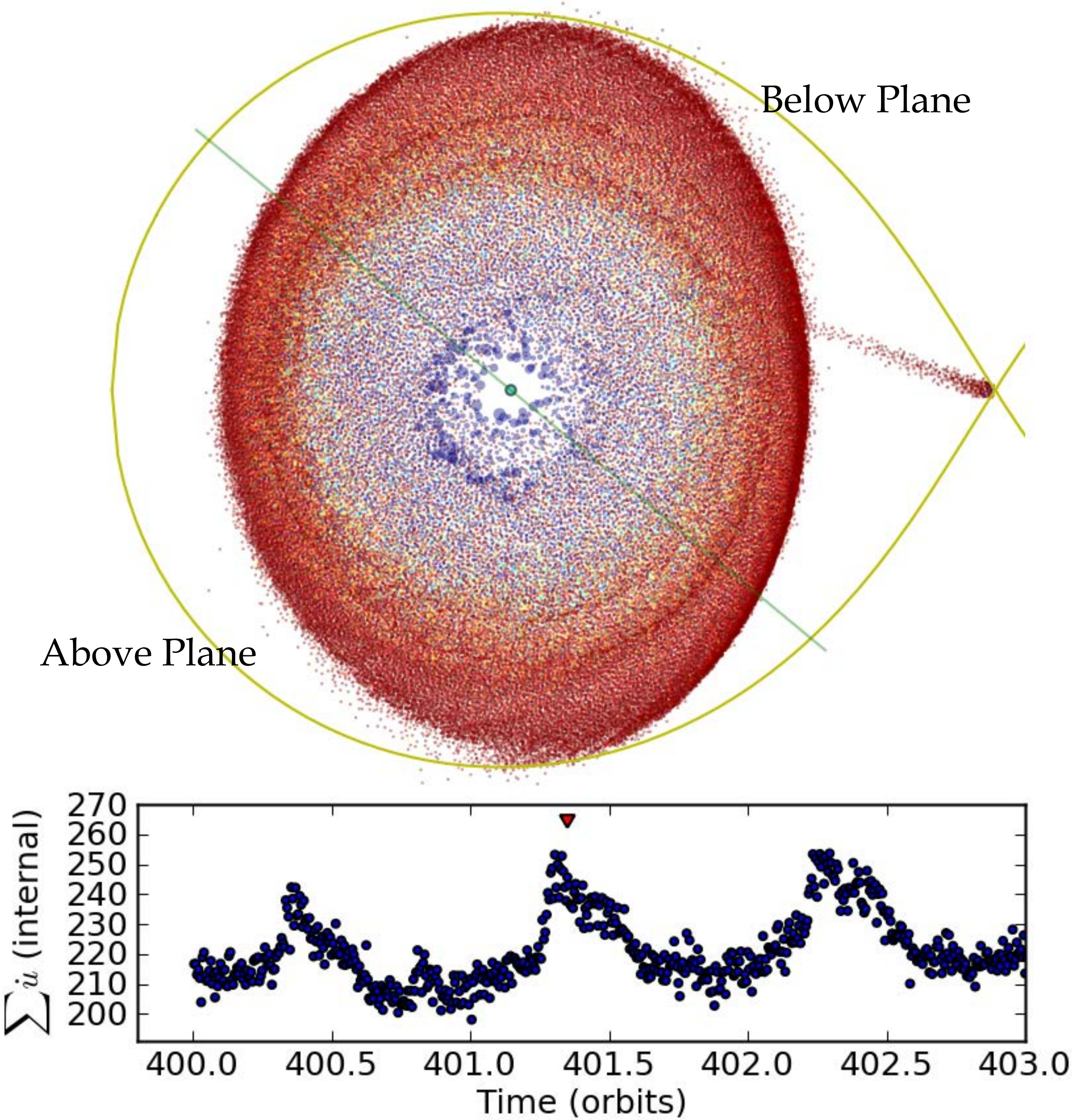

One orbit of a superhumping accretion disk. Frame numbers are indicated above the simulation light curve in the bottom panel. Note that 1 orbit is slightly shorter than the superhump period. Particles color-coded by luminosity. Note two sources of luminosity modulation, disk (frames 1, 6) and stream (frame 4).

# Numerical Simulations of Apsidal Superhumps

- http://astro.fit.edu/wood/viz/q20i0_400.404.mov
- http://astro.fit.edu/wood/viz/q20i80_400.404.mov

# Negative Superhump Period Deficit

$$\epsilon_- = \frac{P_{orb} - P_-}{P_{orb}}$$



# Numerical Simulations of Nodal Superhumps

- http://astro.fit.edu/wood/viz/q40ws400.403i80.mov

# Superhump Summary

- Positive (apsidal) superhumps result from accretion disk flexing (oscillation) in response to tidal driving at 3:1 co-rotation resonance
  - Source 1: dissipation in the periodically compressed and high-shear region opposite the secondary (*disk superhumps*)
  - Source 2: dissipation at the bright spot modulated as the spot sweeps around the rim of the flexing disk (*stream/late superhumps*)
    - this second source will be more important for AM CVns because of the physically-smaller disks (bright spot always deeper in the potential well of the primary)

# Kepler Stellar Mission

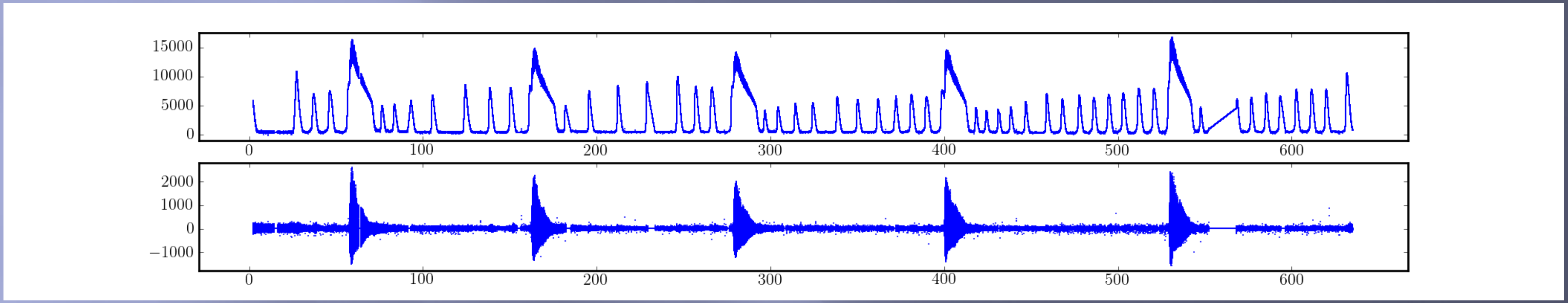
- Although designed for planet hunting, Kepler has provided a "flash flood" of data on pulsating and binary stars
- Well over ½ the publications to date have been stellar-focused, not exoplanetary.
- There are 16 known cataclysmic variables in the Kepler field, including one AM CVn object
- Data to-date are redefining how we think about CVs and will be touchstones for decades to come

# V344 Lyr and V1504 Cyg

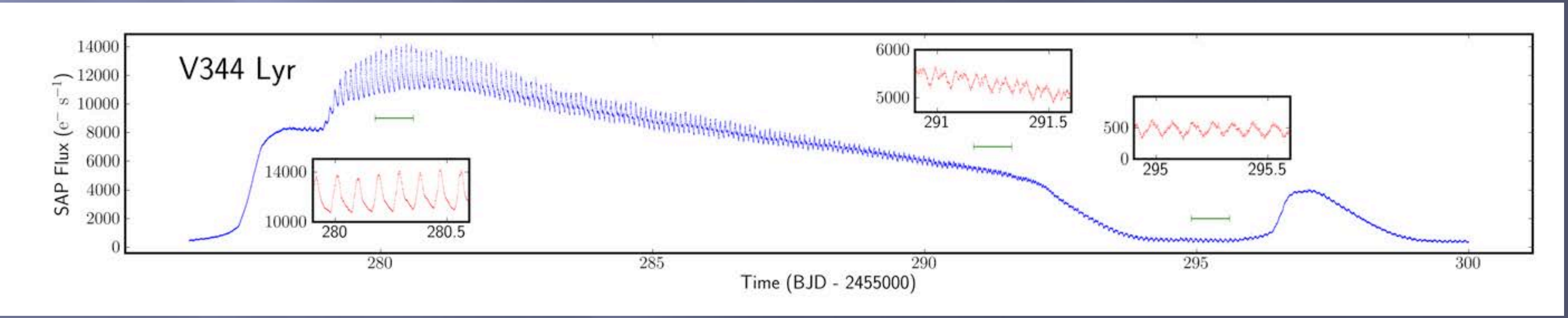
- "Rosetta Stones" for CV studies
  - Dwarf nova and superoutbursts
  - Positive and Negative superhumps ($P_+$ and $P_-$)
  - Orbital periods ($P_{orb}$)
  - Detailed results on frequency and phase evolution of $P_+$ and $P_-$ $\Rightarrow$ insight to astrophysical plasma viscosity
  - Both Observed continuously at short cadence (1-min) for 3 years and counting (1.5 million data points each)!
  - Kp ~ 18 to 14 for both

# V344 Lyr

Top panel: Raw light curve showing DN outbursts and Superoutbursts
Bottom panel: Residual light curve when outbursts removed (high pass filter)

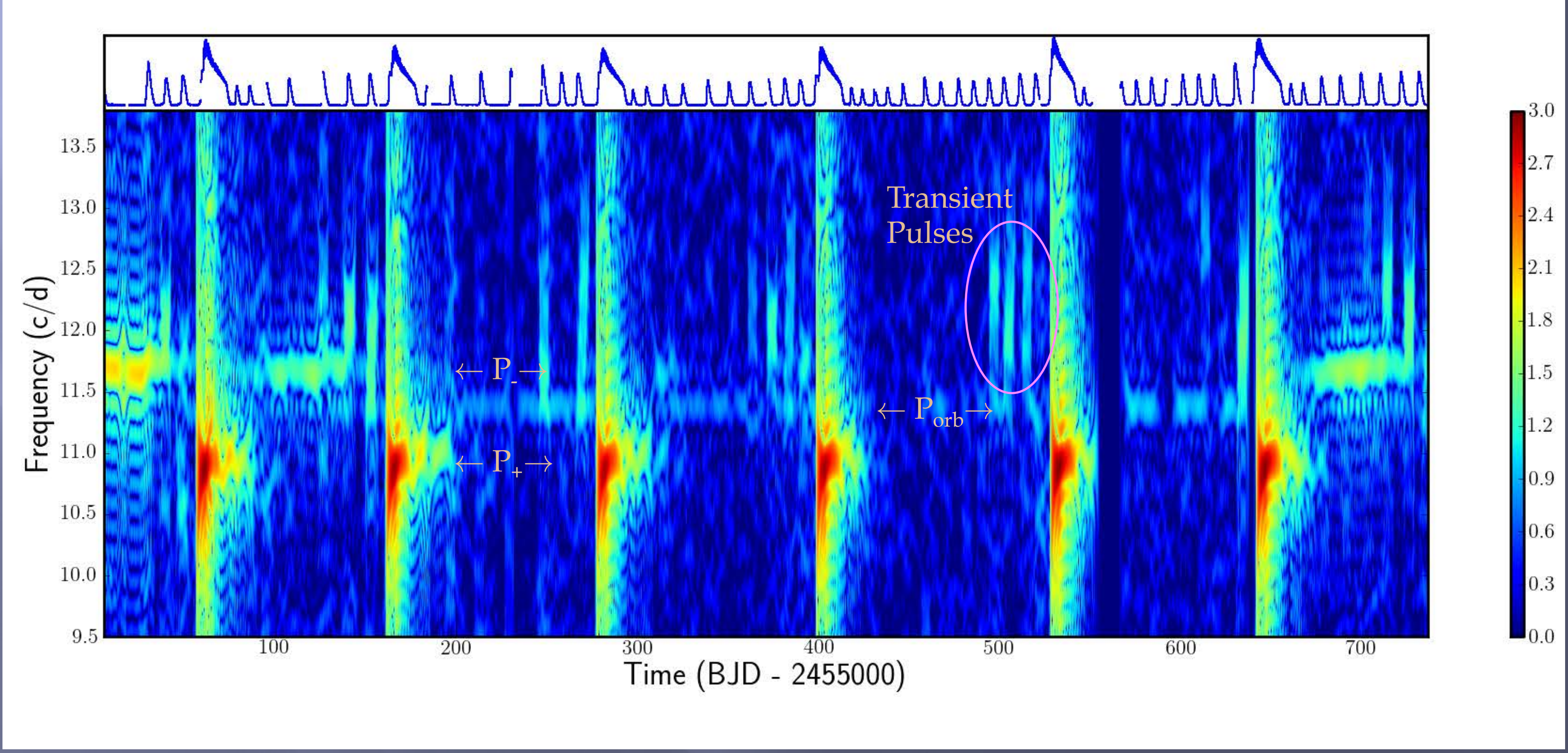


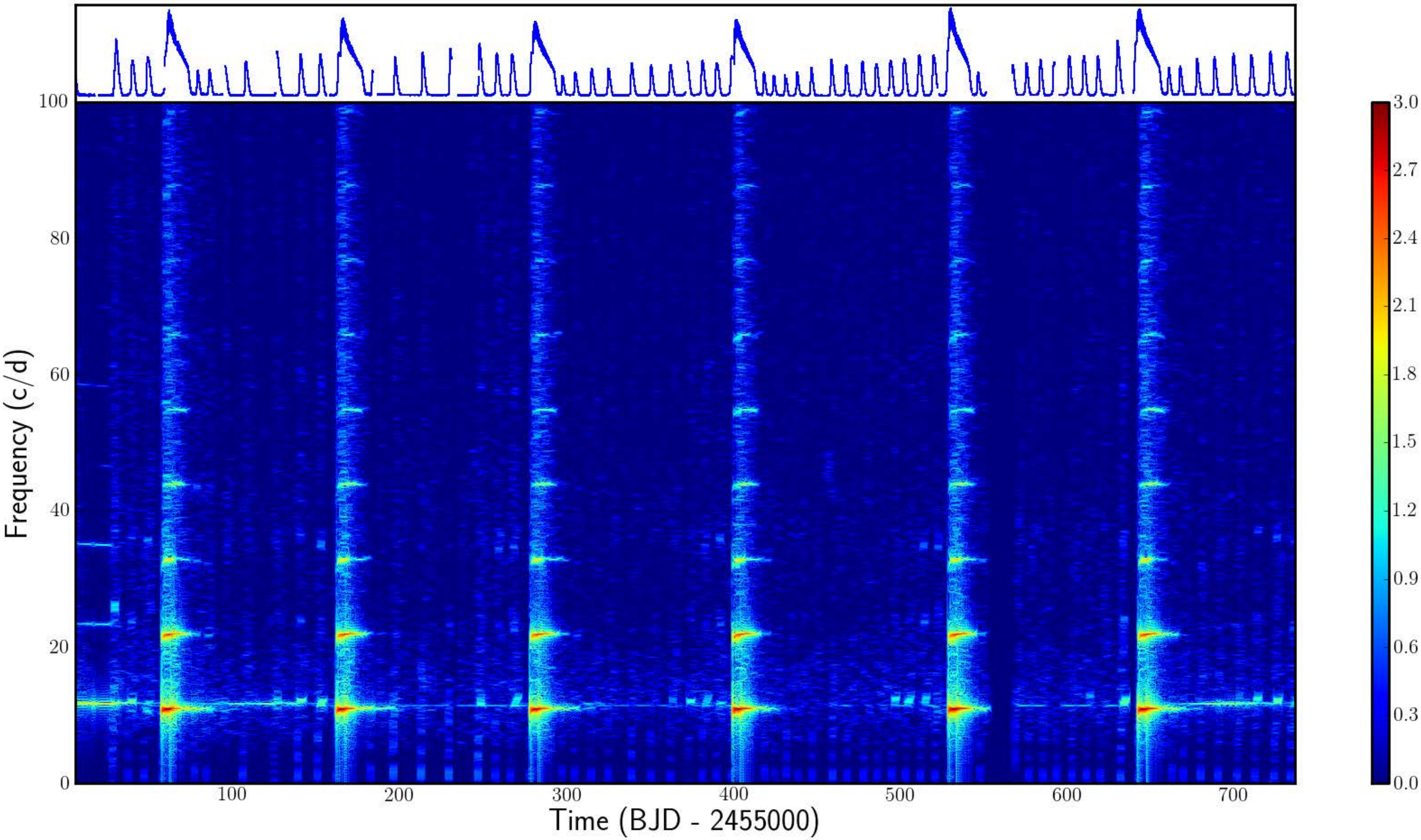
Superoutburst and superhumps. Insets show (i) disk superhumps (ii) transition region, and (iii) stream/late superhumps at quiescence.

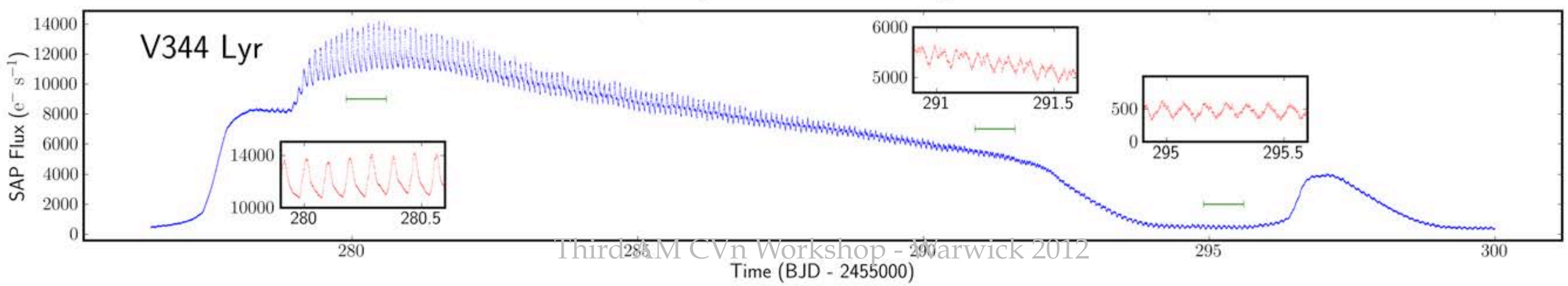


# V344 Spectrogram: Q2-9

- Fourier transform 5-day subsets of residual light curves
- Shift ½ day between transforms
- Result ⇒ “Spectrogram”
- Spectrogram below shows the fundamental periods of interest

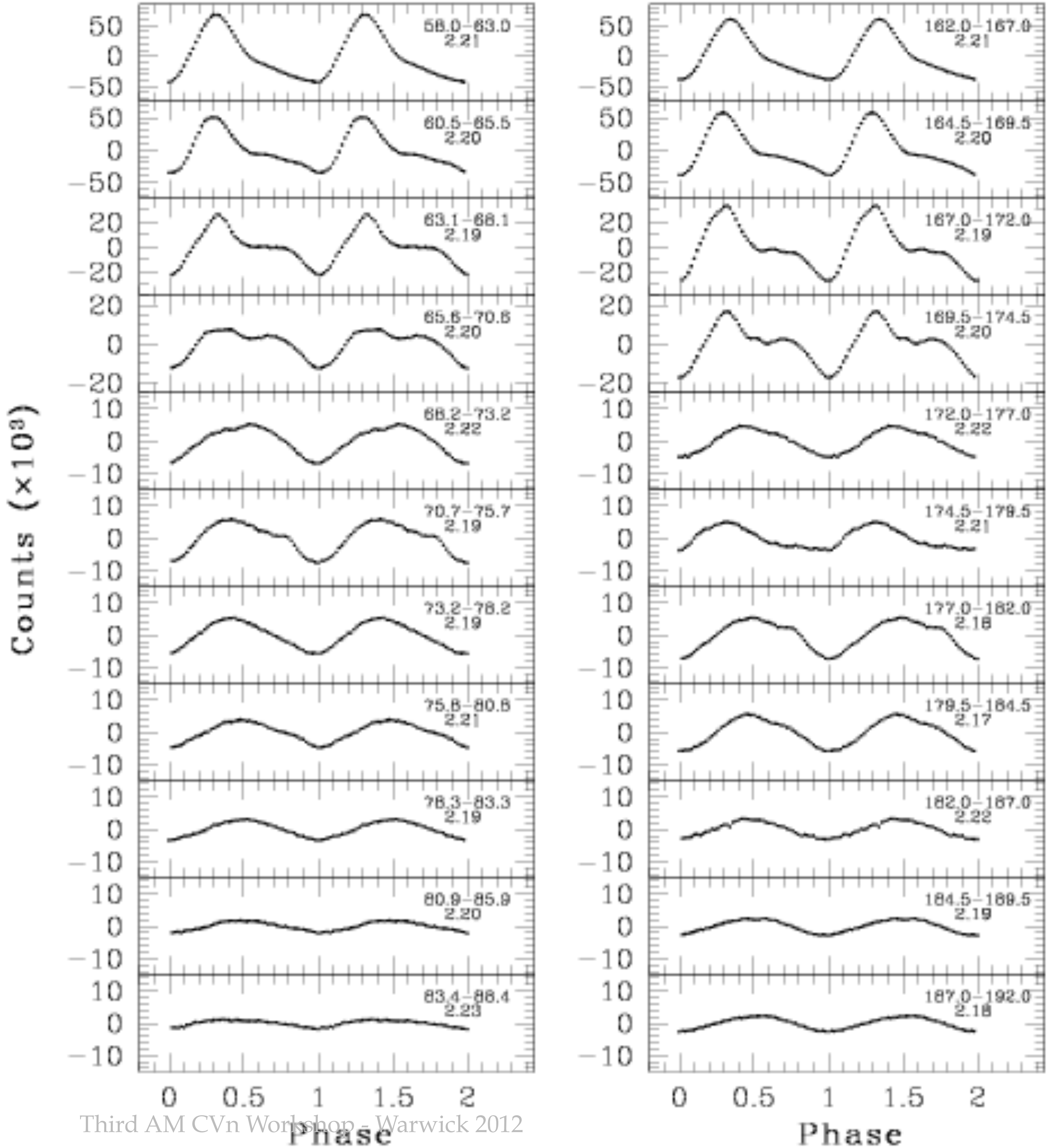



Frequency (c/d)
Time (BJD - 2455000)
0
20
40
60
80
100
100
200
300
400
500
600
700
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0


V344 Lyr
SAP Flux (e⁻ s⁻¹)
Time (BJD - 2455000)
14000
12000
10000
8000
6000
4000
2000
0
280
285
290
295
300
14000
10000
280
280.5
6000
5000
291
291.5
500
0
295
295.5

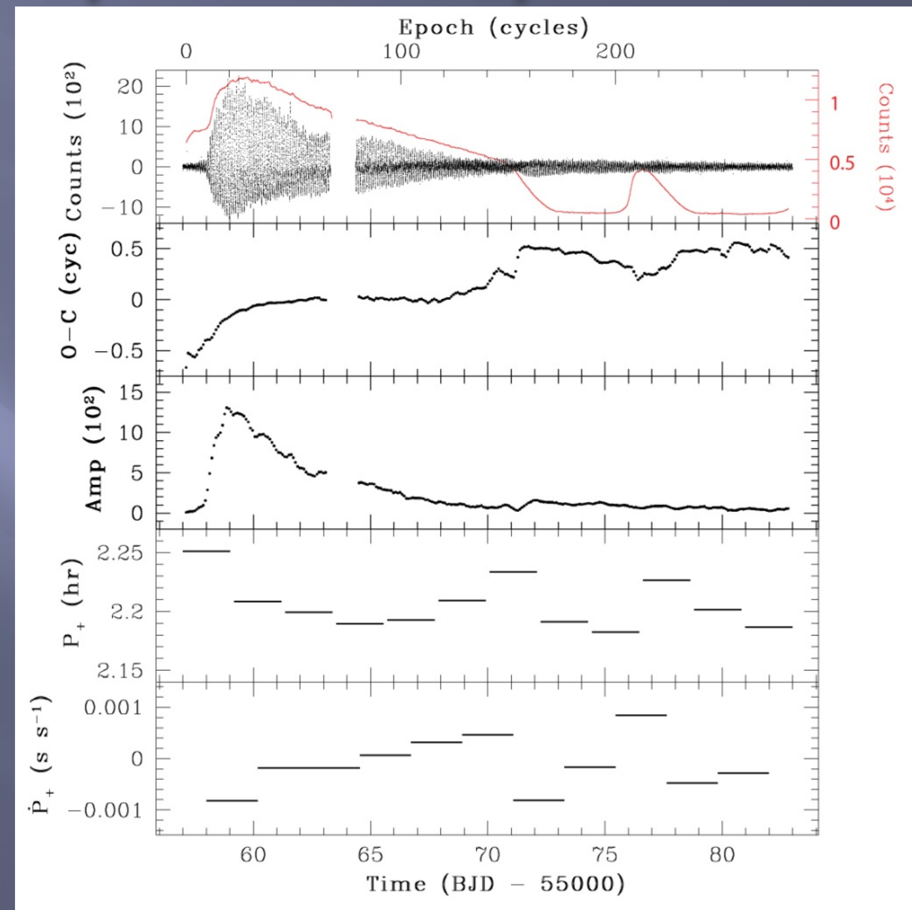
# Average Light Curve Pulse Shapes for first 2 Superoutbursts in V344 Lyr

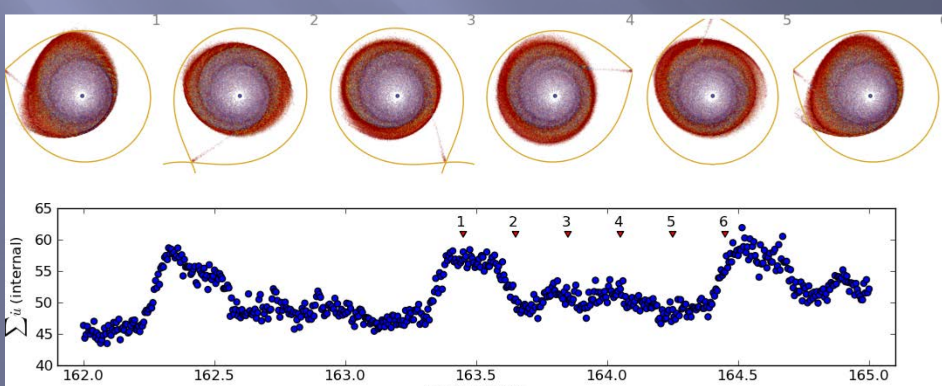
Note transition from disk to stream sources



# O-C phase diagrams, periods and dP/dt for positive superhumps in V344 Lyr

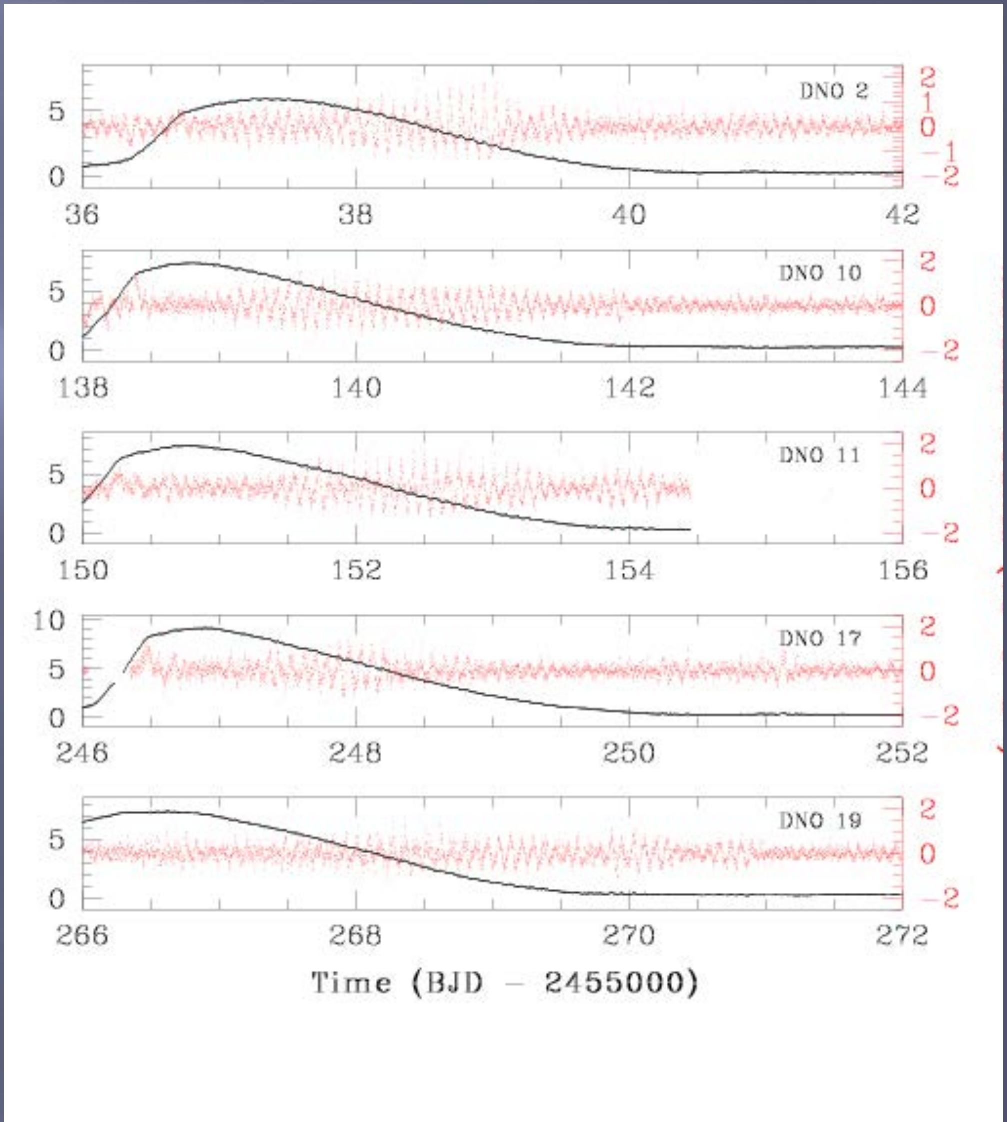
- O-C is "observed minus calculated" → probes period & phase variations
- $P_+$ long during saturation phase – disk mass weighted to large radii
- After ~20 cycles, mass weighting to smaller radii, so $P_+$ decreases
- After ~110 cycles, disk SH fade during transition to low state
- Stream SH begin to dominate, yielding ~0.5 phase shift by cycle ~150
- DN outburst at day 75 pushes mass out in radius, increasing $P_+$
- Typical for V1504 as well



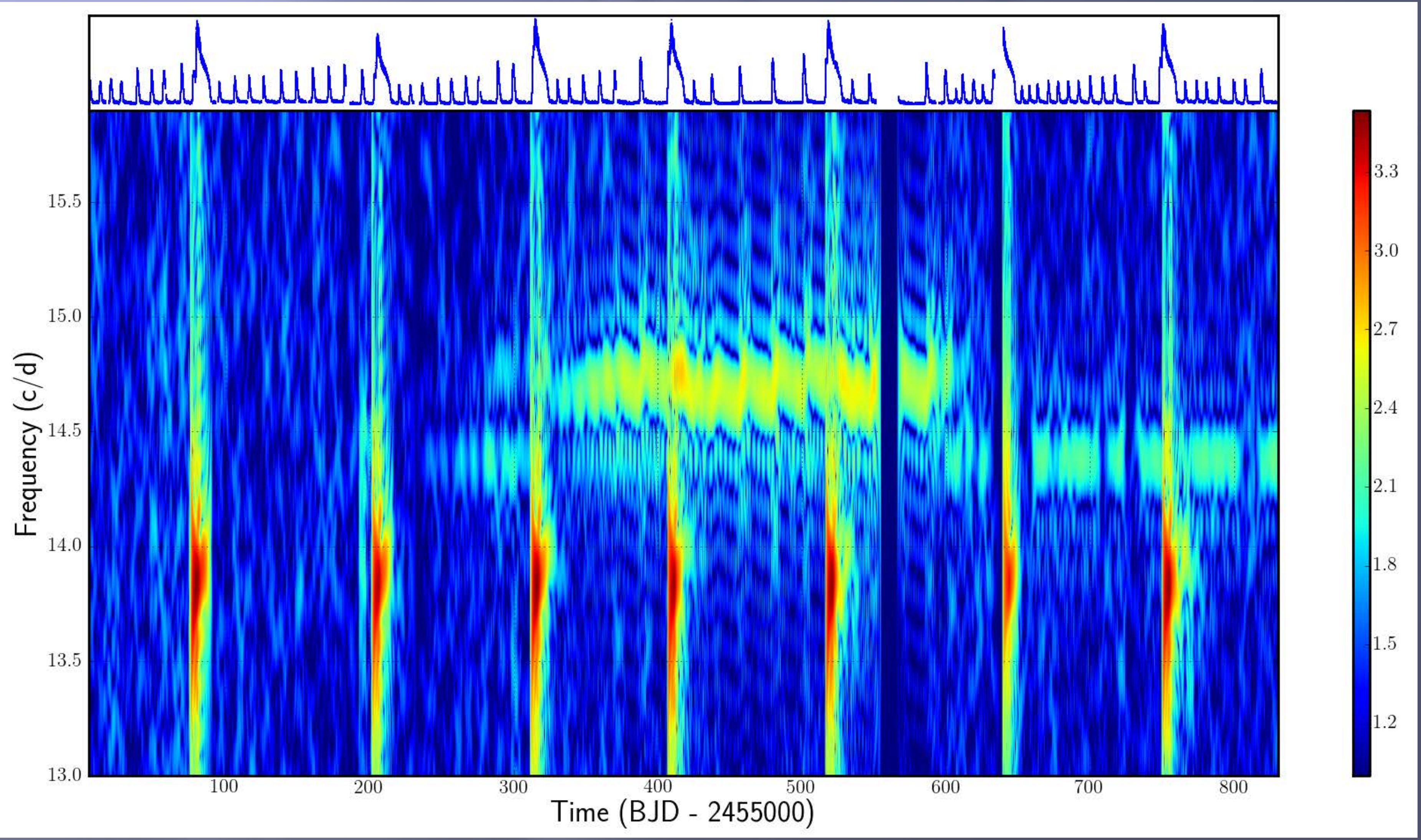



# Transient Pulses in V344 Lyr

- Some DN outbursts late in supercycle appear to trigger transient pulses
- Frequency > $\nu_{-}$
- Perhaps outer disk kicked out of orbital plane by magnetic field of secondary(?)
- Source of disk tilt currently not settled
- Working to model the effect … stay tuned



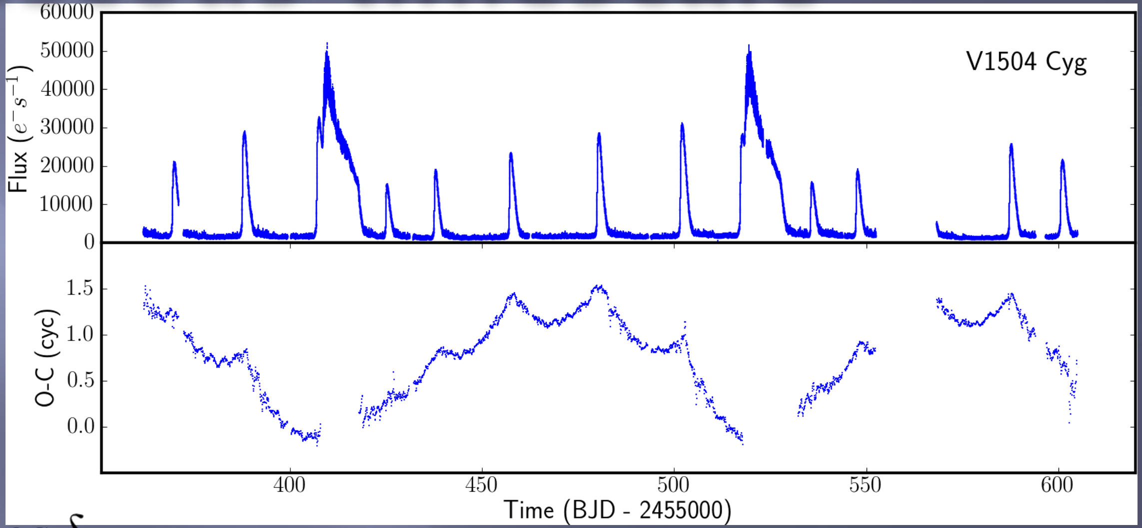
# V1504 Cyg Spectrogram



# V1504 Cyg & V344 Lyr Sonifications

- http://astro.fit.edu/wood/viz/V1504_Q210_Sonification720.mp4
- http://astro.fit.edu/wood/viz/V344Lyr_Superhumps-Audioization.mp4
- Email matt.wood61@gmail.com for more information

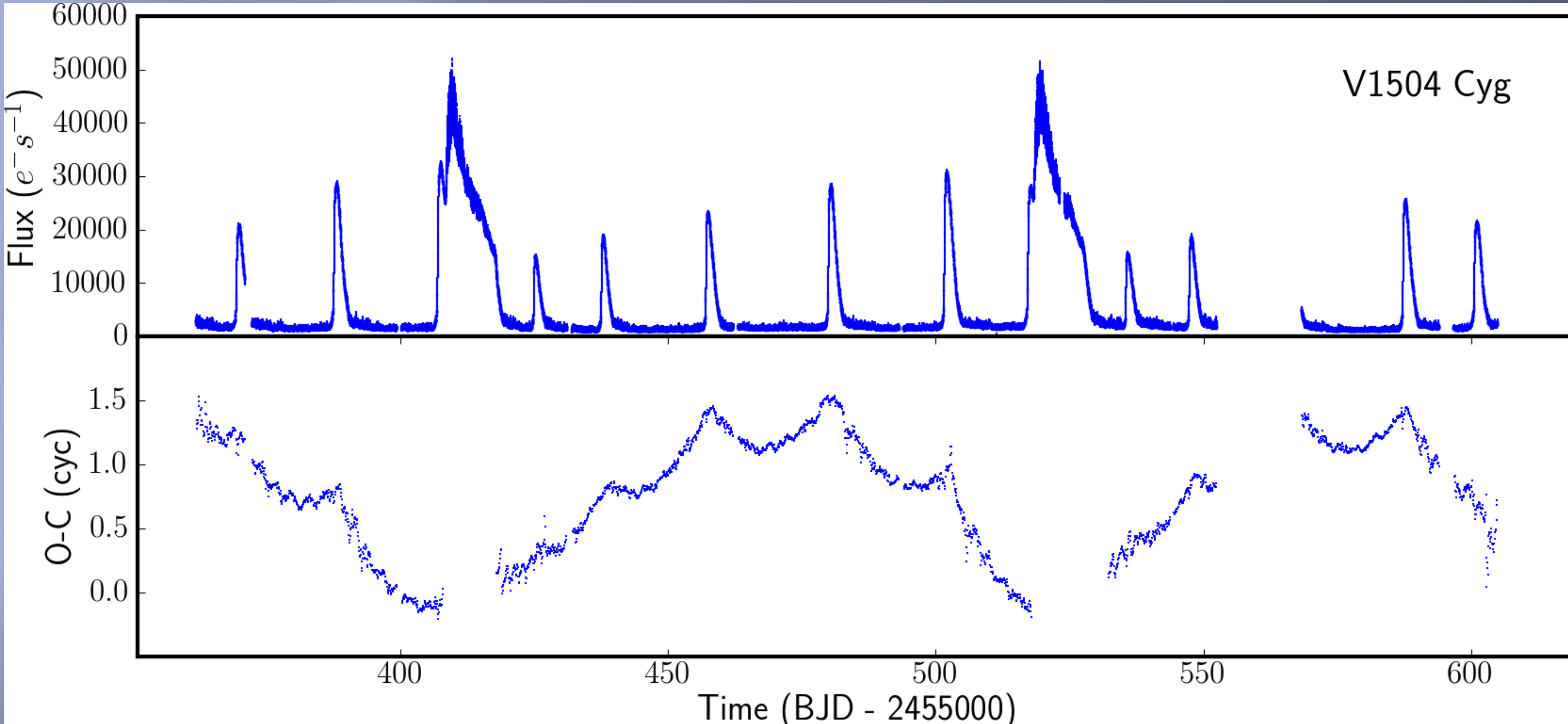
# Negative Superhumps: A Probe of the viscous timescale

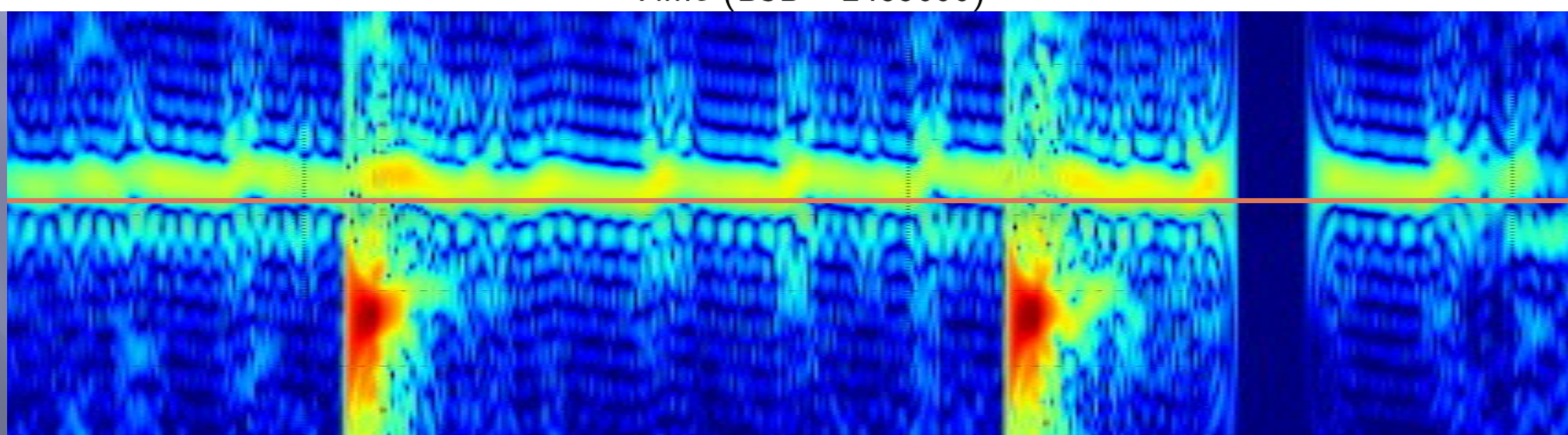



- O-C diagram shows concave up shape between DN outbursts → $P_-$ increasing, ⇒ disk precession rate is slowing between DN
- Disk Precession rate (e.g., Larwood 1998)

$$\omega_p = -\frac{3}{4}\frac{GM_2}{a^3}\frac{\int \Sigma r^3\,dr}{\int \Sigma\Omega r^3\,dr}\cos\delta$$

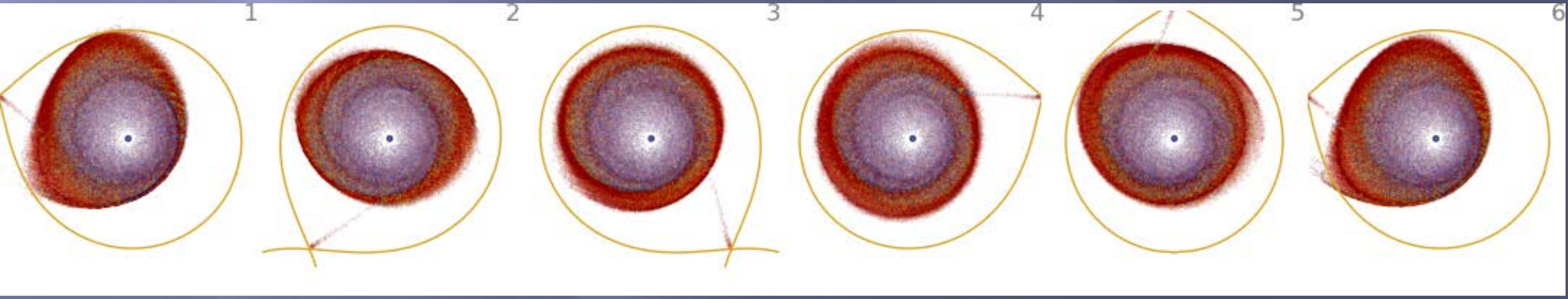
- Accretion onto tilted disk adds mass to *inner* disk, slowing precession rate between DN
- Over supercycle, each DN outburst drains inner disk but pushes weighting out, leading to increasing precession rate over supercycle!
- This result provides clean support for the long-standing model for mass redistribution over a supercycle as discussed earlier
- The details depend upon the astrophysical viscosity operating within the plasma … the Kepler data should provide insight to this


V1504 Cyg
Flux ($e^{-}s^{-1}$)
60000
50000
40000
30000
20000
10000
0
O-C (cyc)
1.5
1.0
0.5
0.0
400
450
500
550
600
Time (BJD - 2455000)



# The Nature of AM CVn, HP Lib, and KIC 4547333

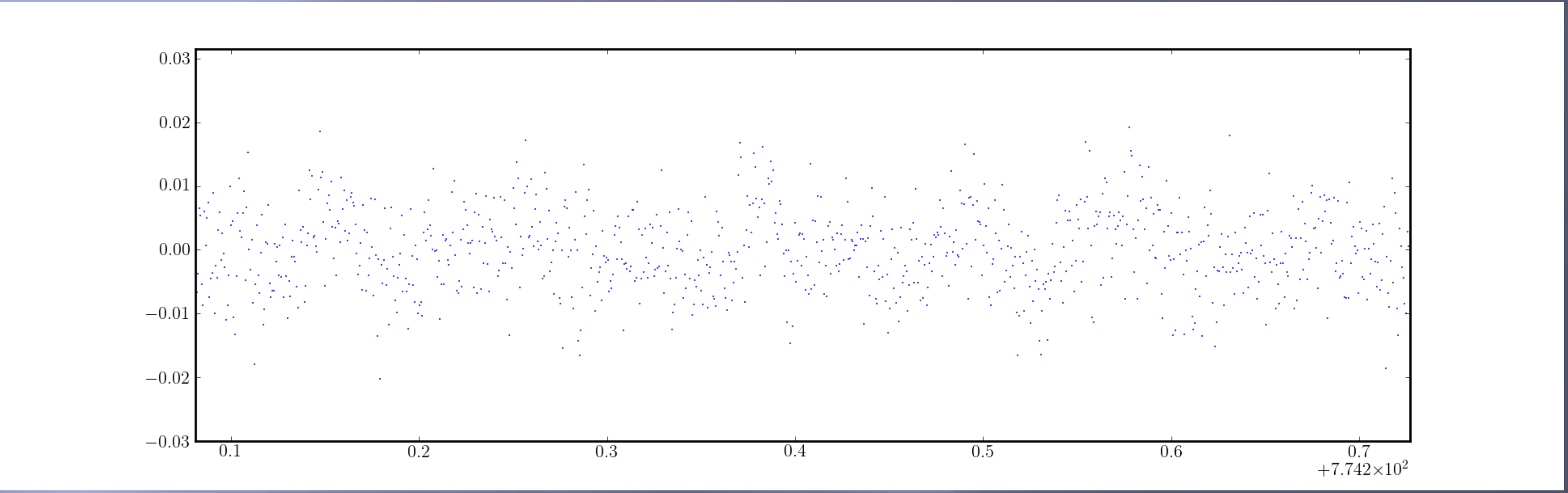
- AM CVn was a puzzle for years because the light curve was dominated by a ~525.5 s period, but the harmonic series indicated a ~1051 s fundamental
- In light of the Kepler results for V344 Lyr, it appears clear that the double humped nature indicates roughly equal contributions by both physical mechanisms – disk and stream.
- Detectable spectroscopically with sufficiently high S/N?



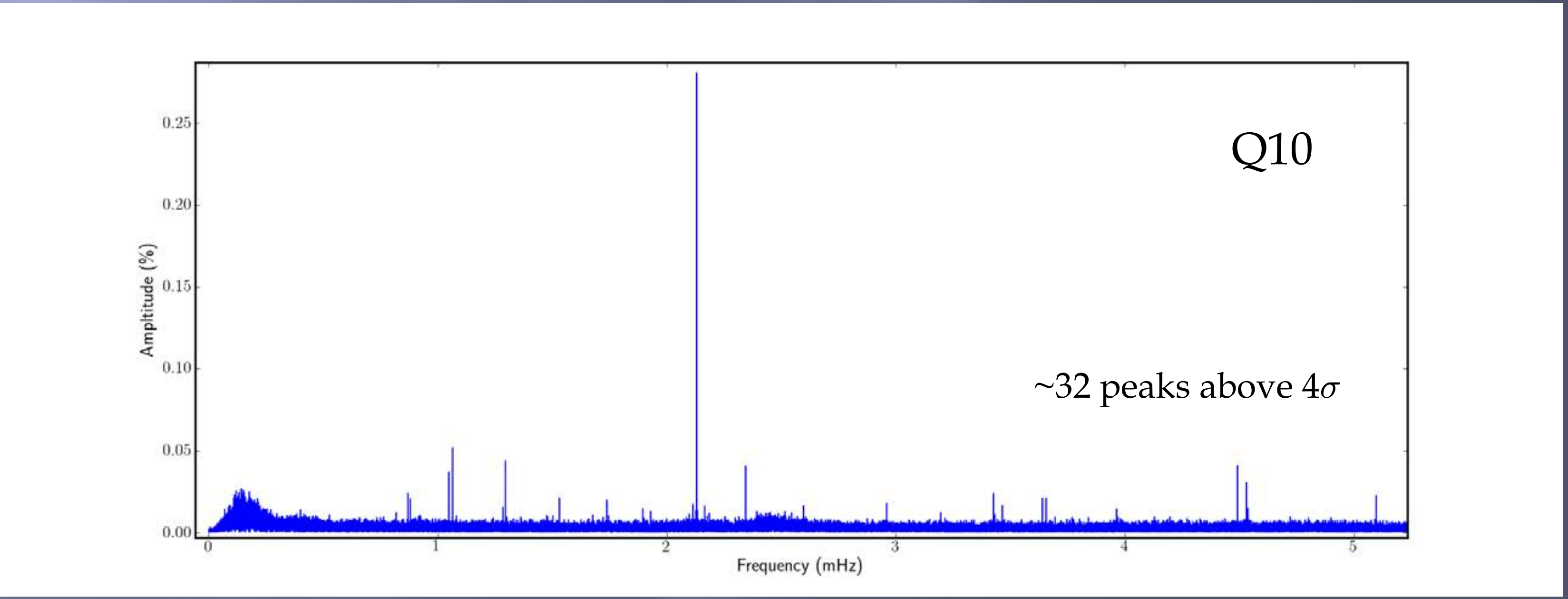
# KIC 4547333 (SDSS J1908+394) The Kepler Field AM CVn (work in progress)

- Announced by Fontaine et al. (2011)
- Initially believed to be a potential compact pulsator
- Observed at SC for Q3.3, then Q5, Q10-11…
- Similar to WD spectrum, but He accretion disk a better fit
- Low inclination i ~ 10-20$^{o}$
- d ~ 257 pc
- dM/dt ~ $5\times10^{-9}$ $M_{\odot}$/yr

# KIC 5457333



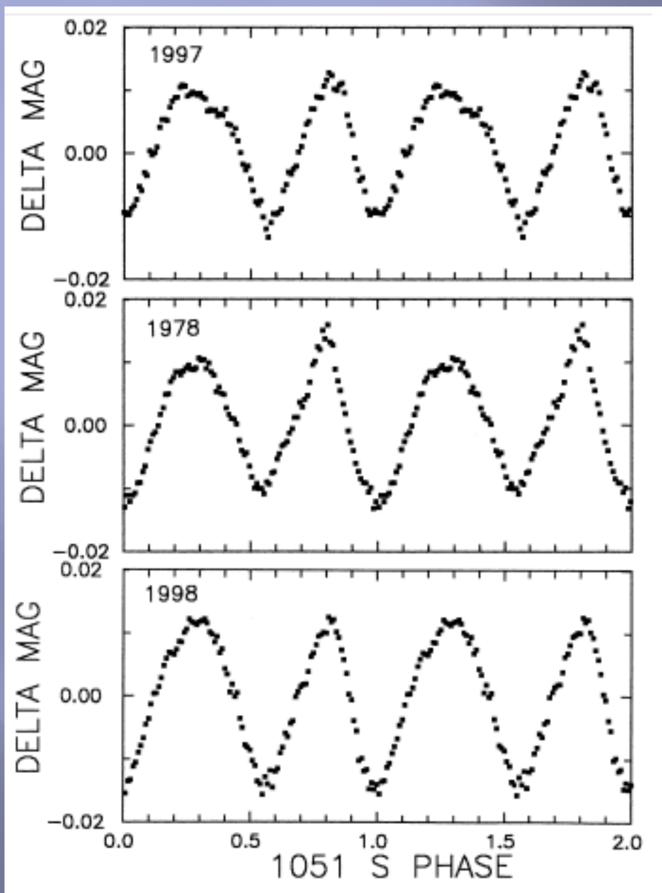
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
0.1
0.2
0.3
0.4
0.5
0.6
0.7
+7.742×10²

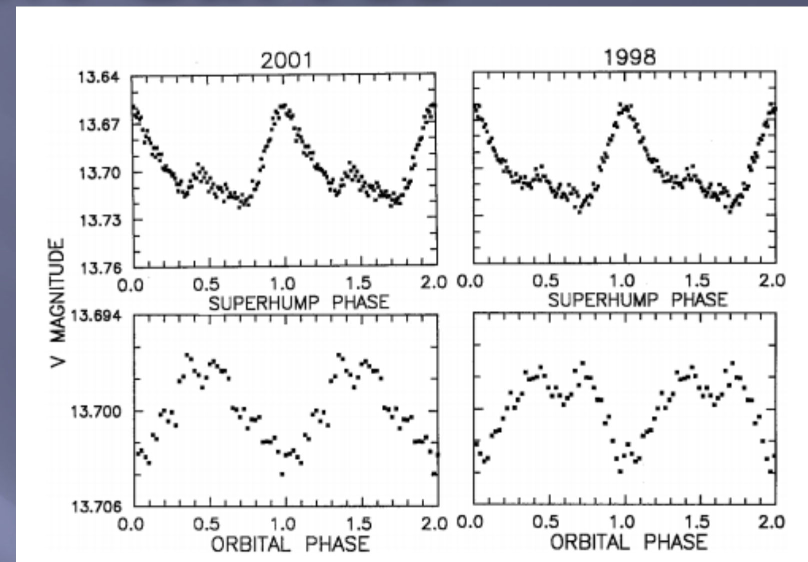
Q10
~32 peaks above 4σ
Amplitude (%)
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
Frequency (mHz)

# Average Light Curves

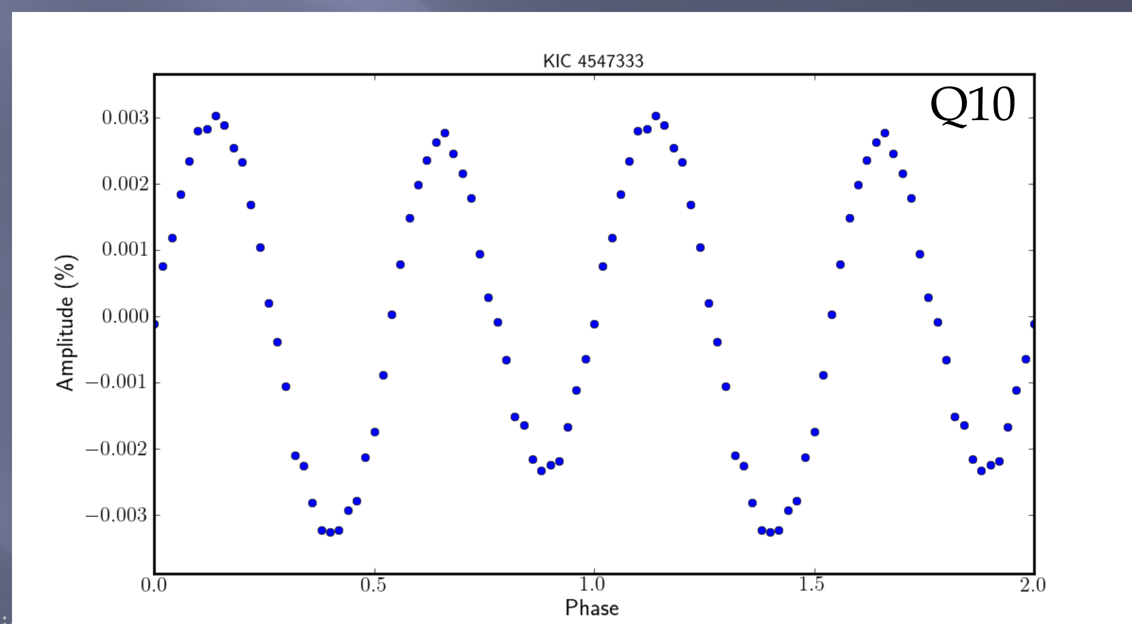
AM CVn




HP Lib

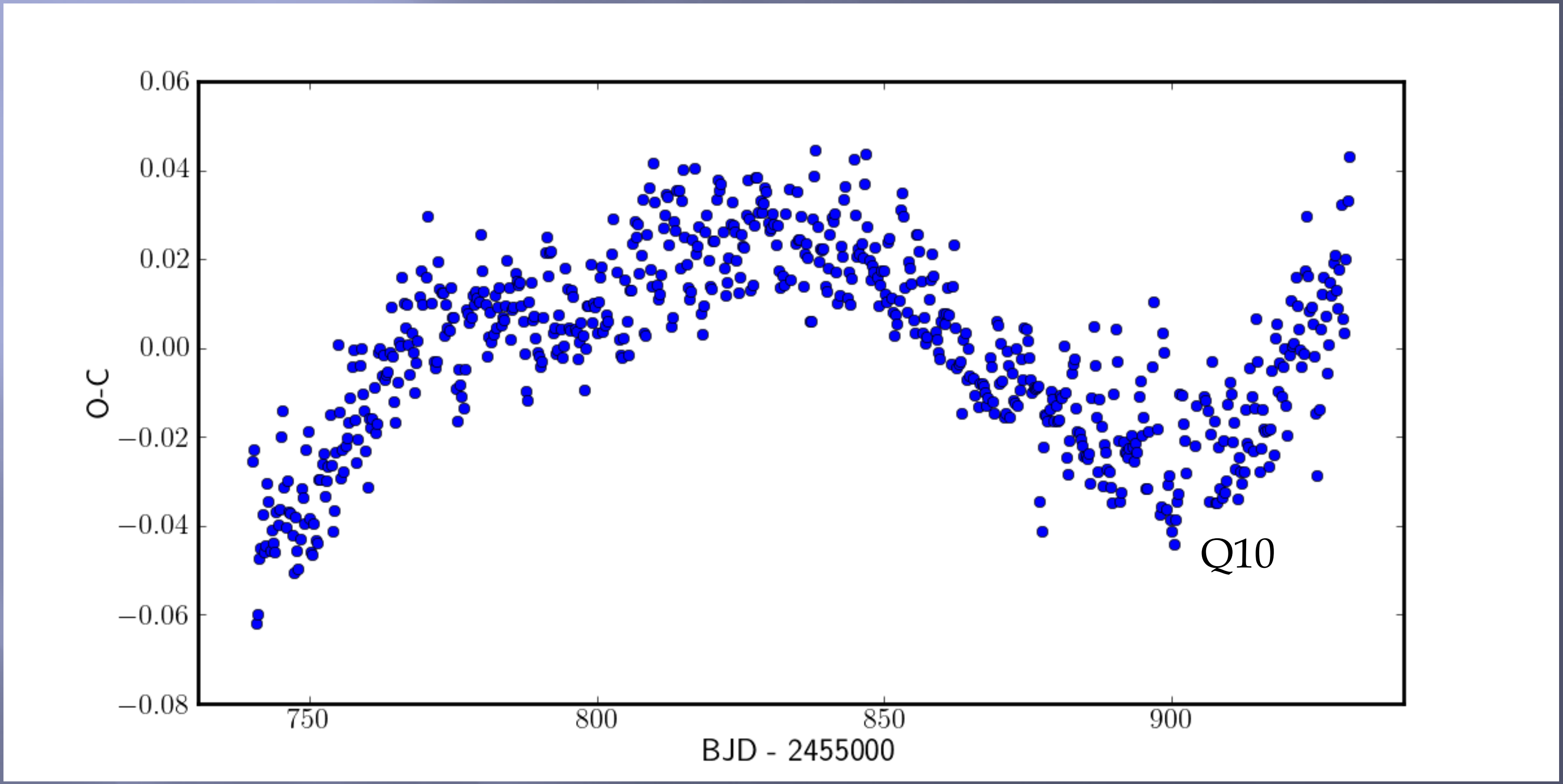



KIC 4547333



# KIC 4547333 – not a DB pulsator

(Or at least not just a DB pulsator …)




Future work: Pre-whiten by SH and check stability of O-C for other periods, check for mean system brightness variations, correlations with O-C …

# The Promise of Kepler CV Research

- Observed periods & eclipses will yield binary and stellar parameters
- Determining the detailed phenomenology of accretion disk outburst cycles of dwarf novae
- Testing viscous accretion disk limit cycle models against quiescent-to-outburst light curves and quantifying mass accretion rates, disk viscosity and other accretion disk properties
- Testing the viscous disk, mass transfer instability and resonant disk models directly against superhump observations – already we believe we must employ a spatially-varying viscosity
- Deeper understanding of the dynamics of apsidal and nodal superhumps
- Characterizing accretion disk flickering
- Time-Series goodness on a high-state AM CVn!

# Questions?