Missing Physics in Simulations of Accretion Disks

(Modified Presentation)

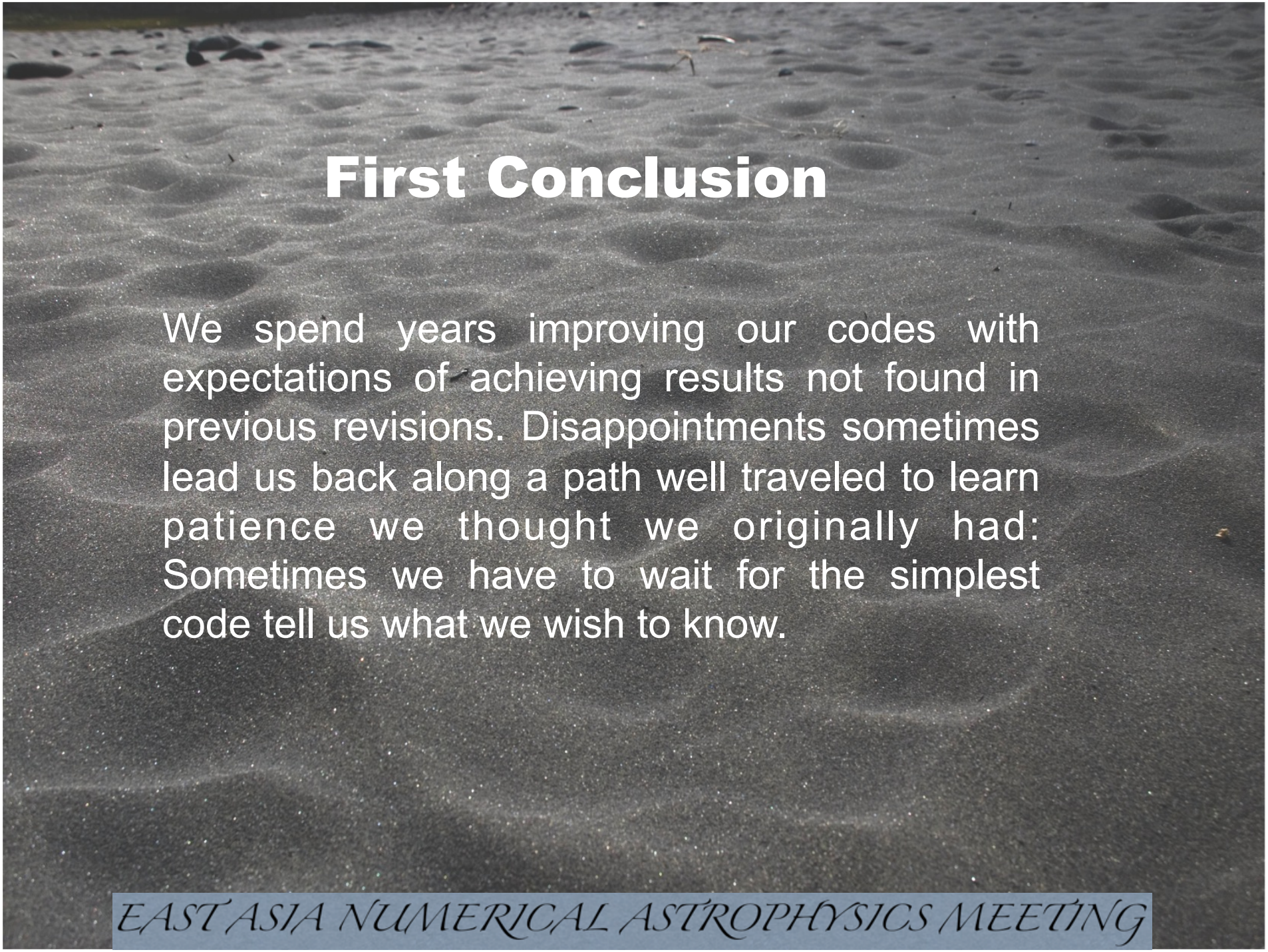
Michele M. Montgomery
University of Central Florida (UCF)
Orlando, Florida, USA

"Expectations are disappointments in training."
Prof. Barry Schwartz, Psychologist, Swarthmore

EAST ASIA NUMERICAL ASTROPHYSICS MEETING

October 29 - November 2, 2012

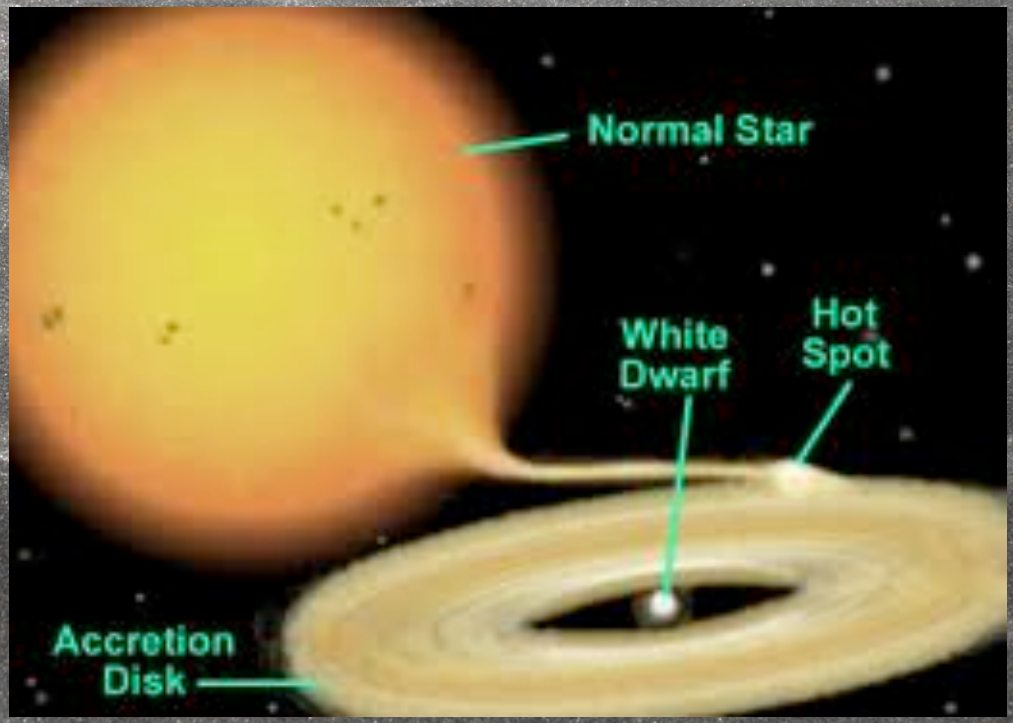
University of Central Florida



First Conclusion

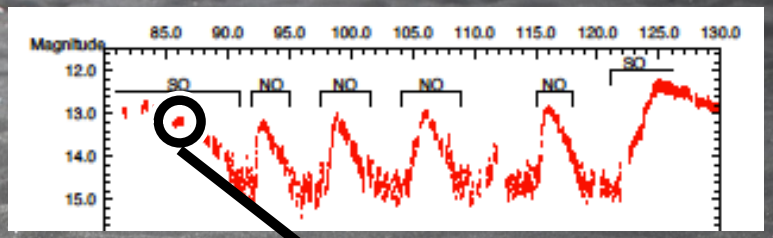
We spend years improving our codes with expectations of achieving results not found in previous revisions. Disappointments sometimes lead us back along a path well traveled to learn patience we thought we originally had: Sometimes we have to wait for the simplest code tell us what we wish to know.

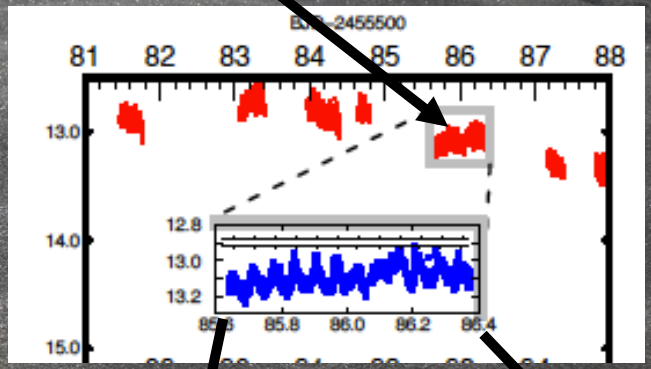
Target: Non-Magnetic Cataclysmic Variables (CVs)



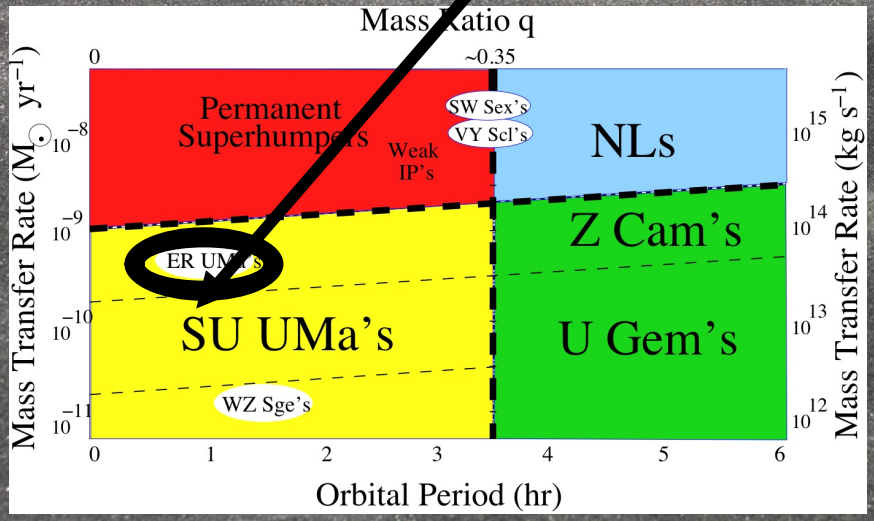
NASA

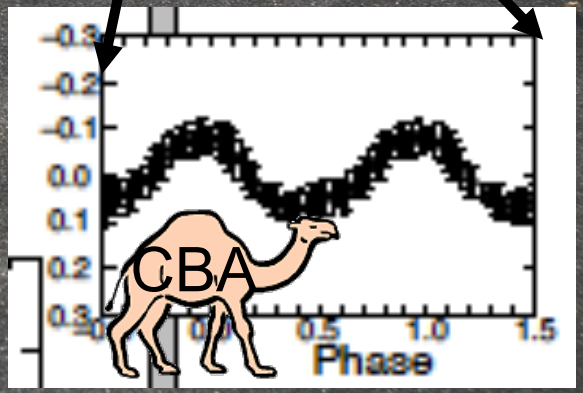
Observations: Normal Outbursts (NO), Superoutbursts (SO), Superhumps





ER UMa

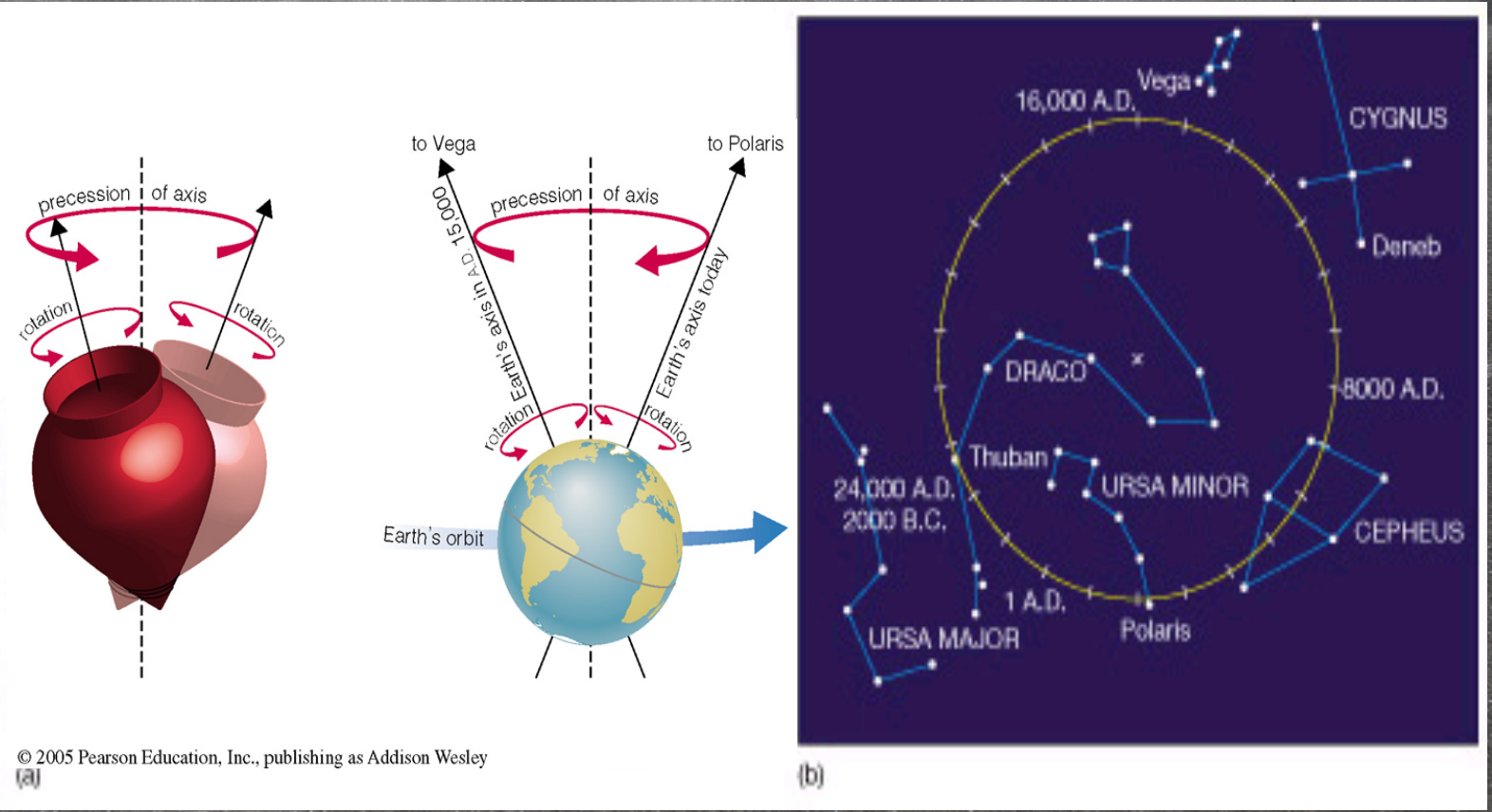




Montgomery (2009 MNRAS), Osaki (1985)

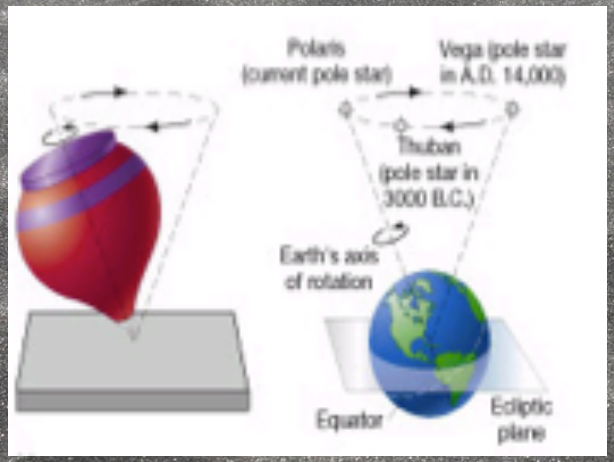
Ohshima, Kato et al. (2012)

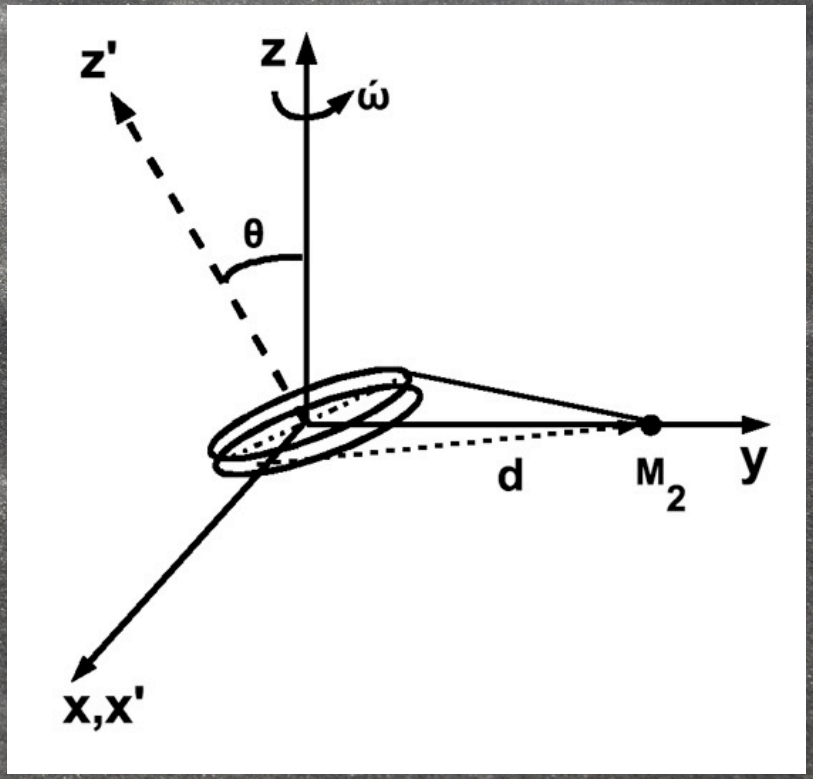
Source to Retrograde Precession & Negative Superhump Connection



Montgomery (2009 ApJ)

Source to Retrograde Precession & Negative Superhump Connection

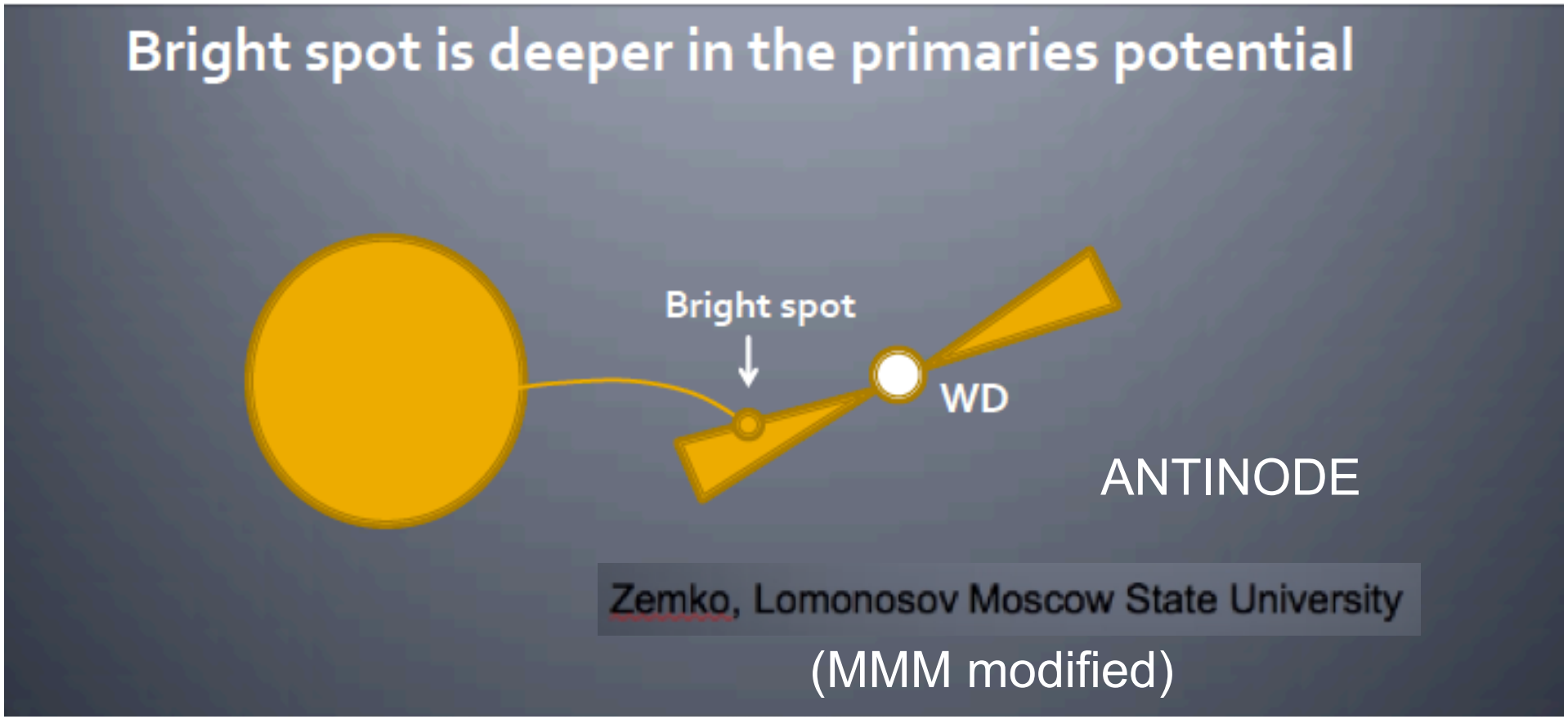




Montgomery (2009 ApJ)

Negative superhumps

Cartoon Model: Large Disk Tilt



Negative superhumps

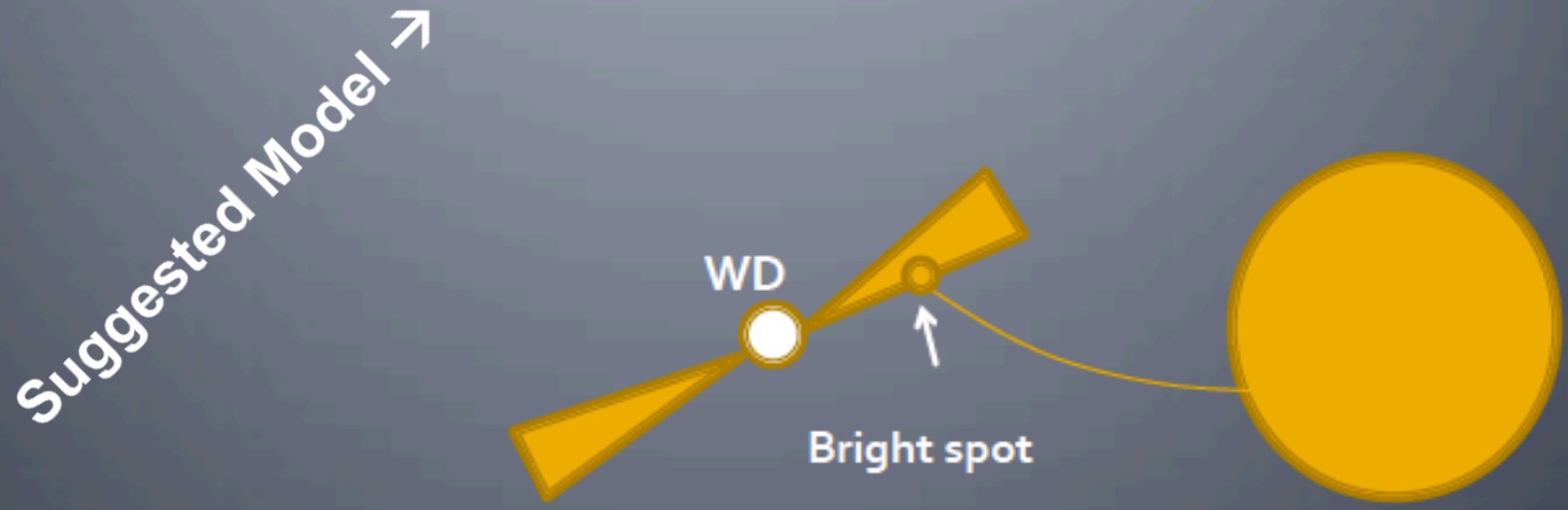
Bright spot is at the disks rim

NODE

Zemko, Lomonosov Moscow State University (MMM modified)

Negative superhumps

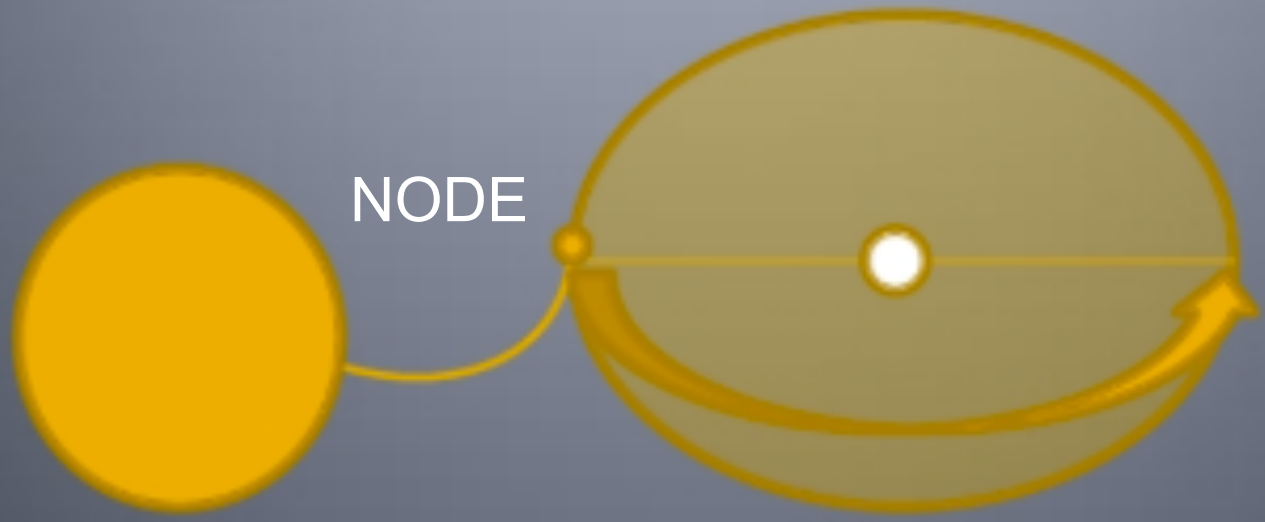
Bright spot is deeper in the primaries potential



ANTINODE

Zemko, Lomonosov Moscow State University (MMM modified)

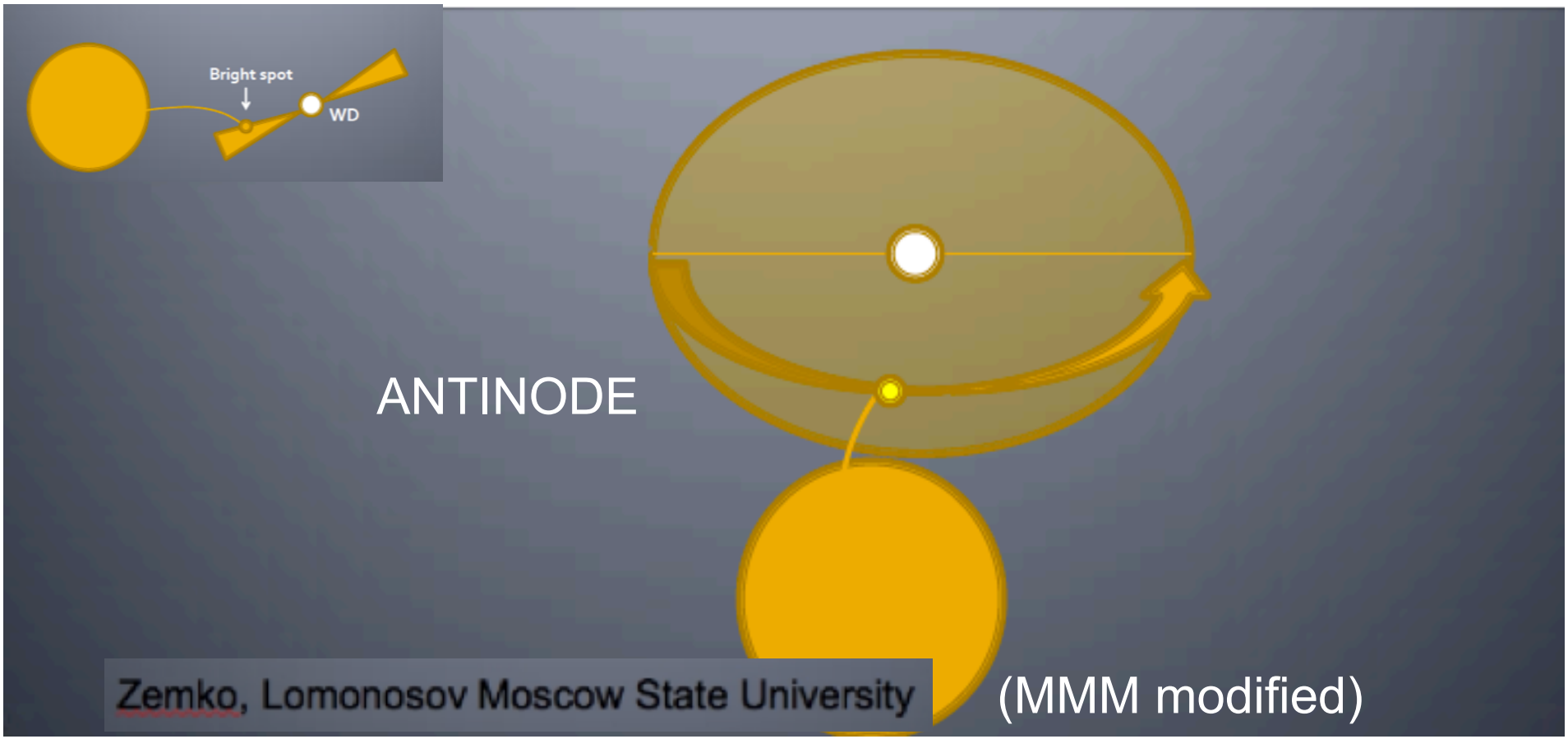
Negative superhumps



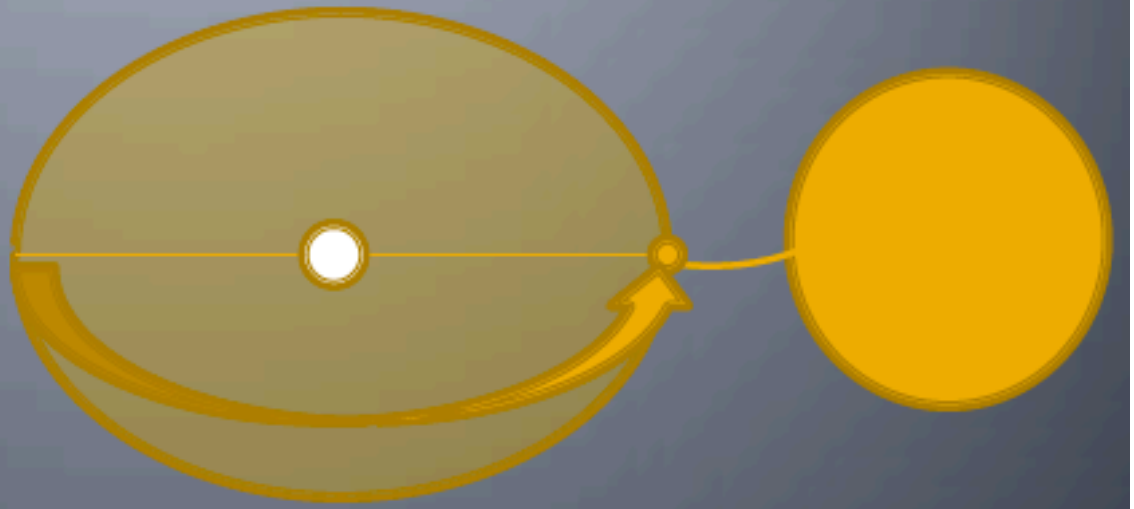
Zemko, Lomonosov Moscow State University

(MMM modified)

Negative superhumps



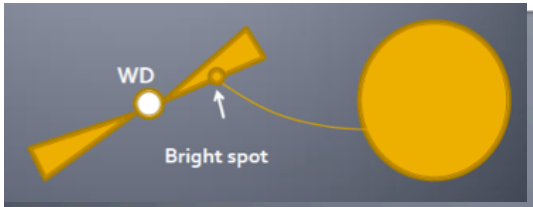
Negative superhumps



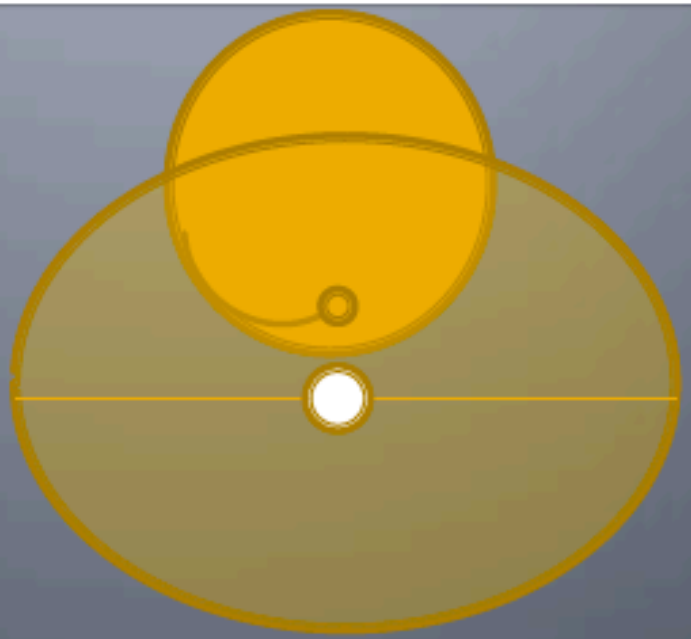
NODE

Zemko, Lomonosov Moscow State University (MMM modified)

Negative superhumps

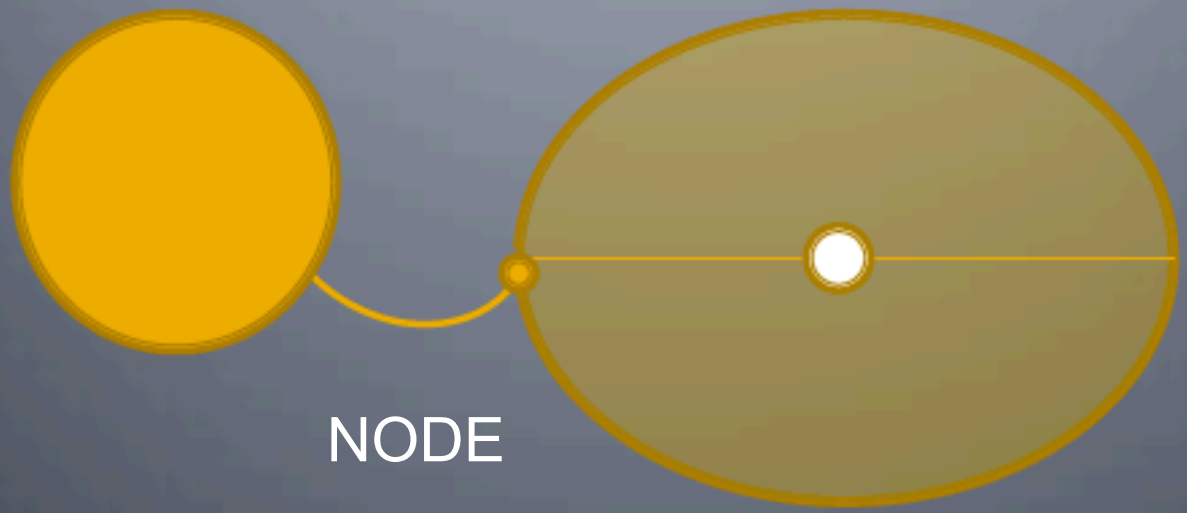


ANTINODE



Zemko, Lomonosov Moscow State University (MMM modified)

Negative superhumps



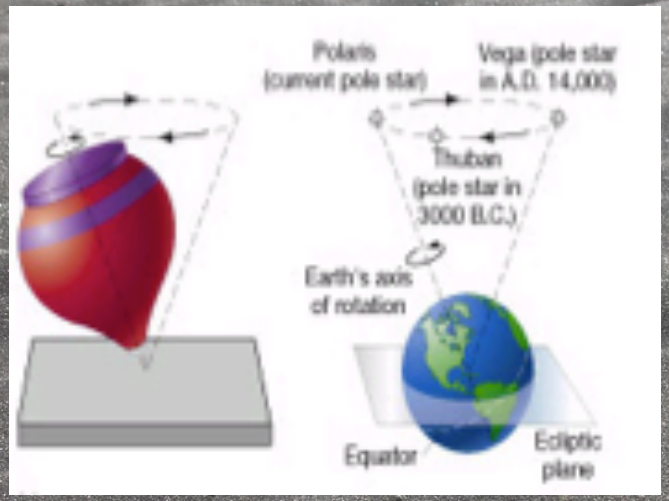
Zemko, Lomonosov Moscow State University (MMM modified)

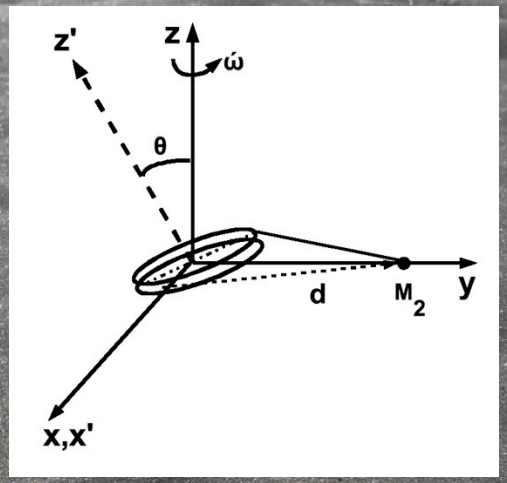
Simulating (Negative) Superhumps & Retrograde Precession

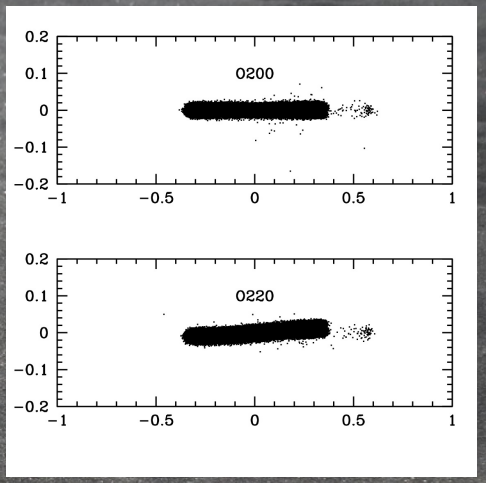
3D Smoothed Particle Hydrodynamic (SPH) Code (Simpson 1995 is base code)

- **No magnetic fields**
- **Ideal gas $P=(\Upsilon-1)\rho u=\rho kT/m$**
- **Particles: equal size, mass, shape**
- **Resolution: 25,000 particles maintained**
- **Inertial frame**
- **Keplerian orbits**
- **Stars are point masses**
- **Particles injected at thermal speed from L1**
- **Numerical Viscosity (Monaghan 1992) on both approaching and receding particles; Shakura & Sunyaev (1973) α-disk, $\alpha\sim0.05$**
- **6 timesteps**

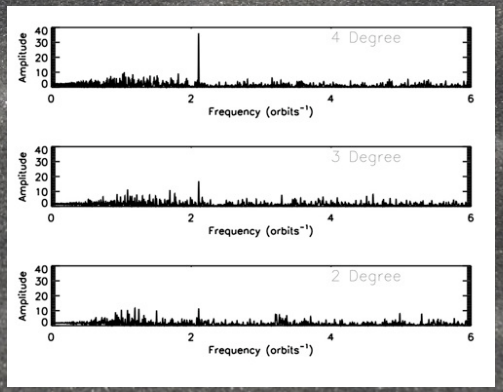
Artificially Induced Negative Superhumps

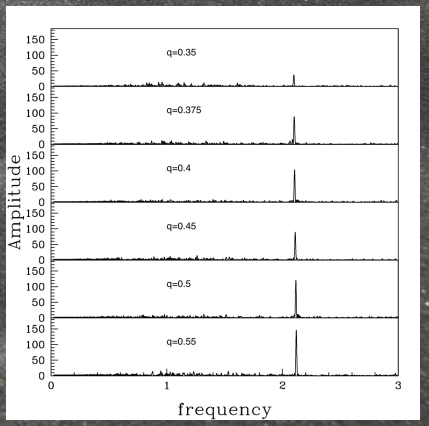


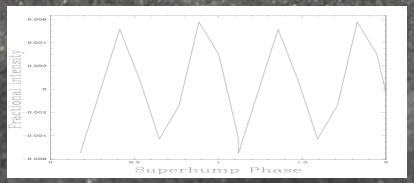




- **Control group →→→→ Artificially Tilted Disk Particle # = 100,000, M_1=0.8$M_\odot$ (Montgomery 2004/2009)**





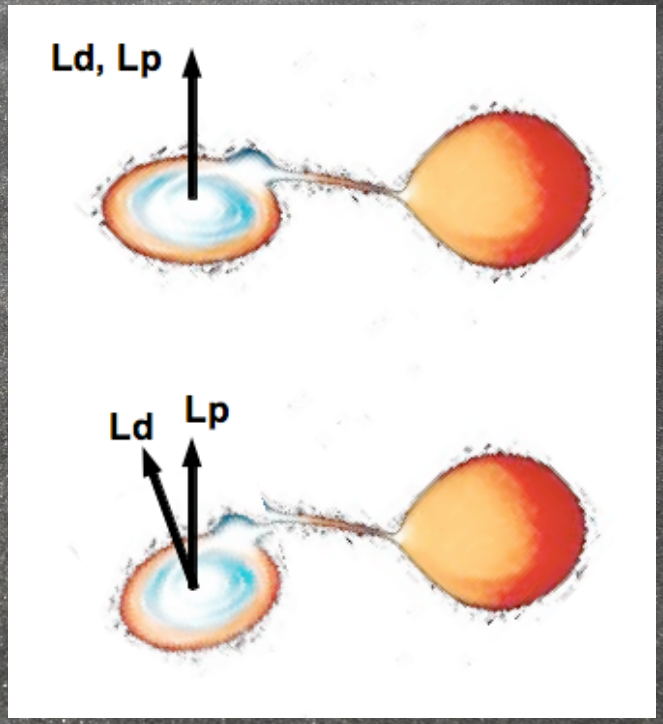


Montgomery (2004, 2009)

Simulating Negative Superhumps: – Expected Disk Evolution Model

t≈0 (disk starts to form, disk and primary axes aligned)

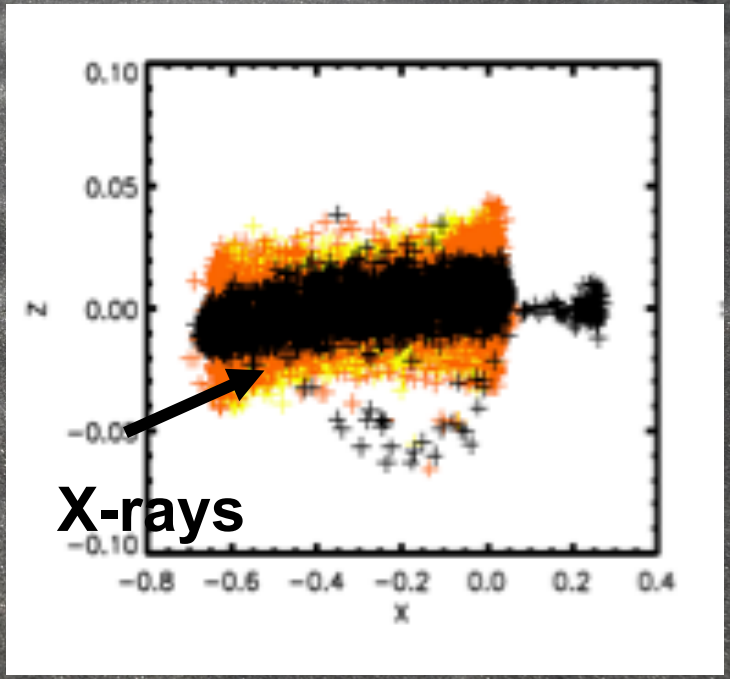
t≈fortnight (disk tilts in simulation of V344 Lyrae in Kepler Field, disk and primary axes unaligned



Ed Sion, Villanova webpage (modified by MMM)

Results: Naturally Generated Negative Superhump Signals after 600 orbits

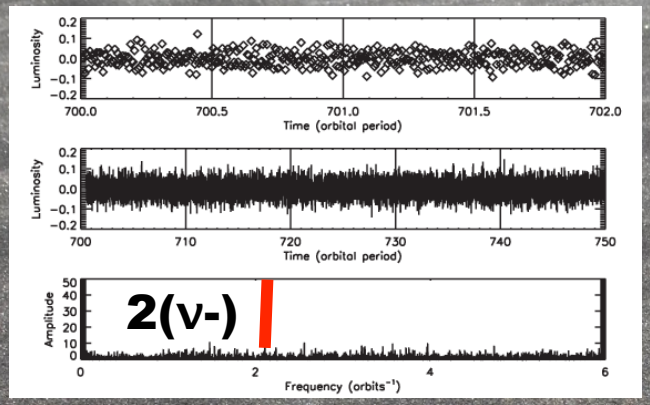
- Natural group →→→→→→ Particle # = 25,000, q=0.4, M_1=0.6$M_\odot$ Naturally Tilted Disks (Montgomery 2012)
  - Tilted
  - Precesses in retrograde direction
  - Negative Superhump signals



Montgomery (2012a ApJ Jan. Letters)

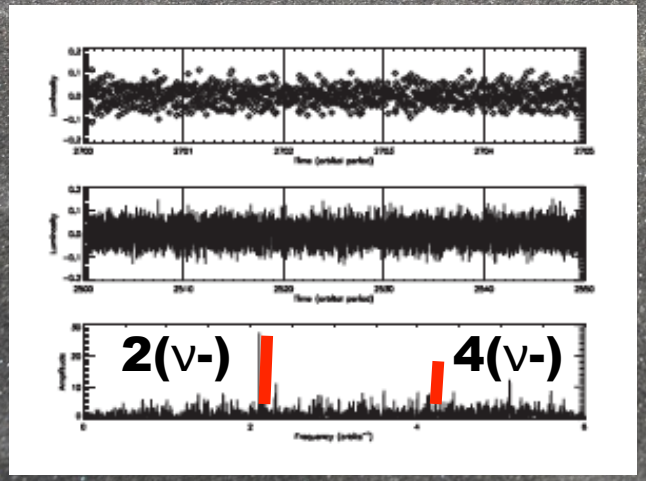
Results: Signals & Precession

of Orbits~700

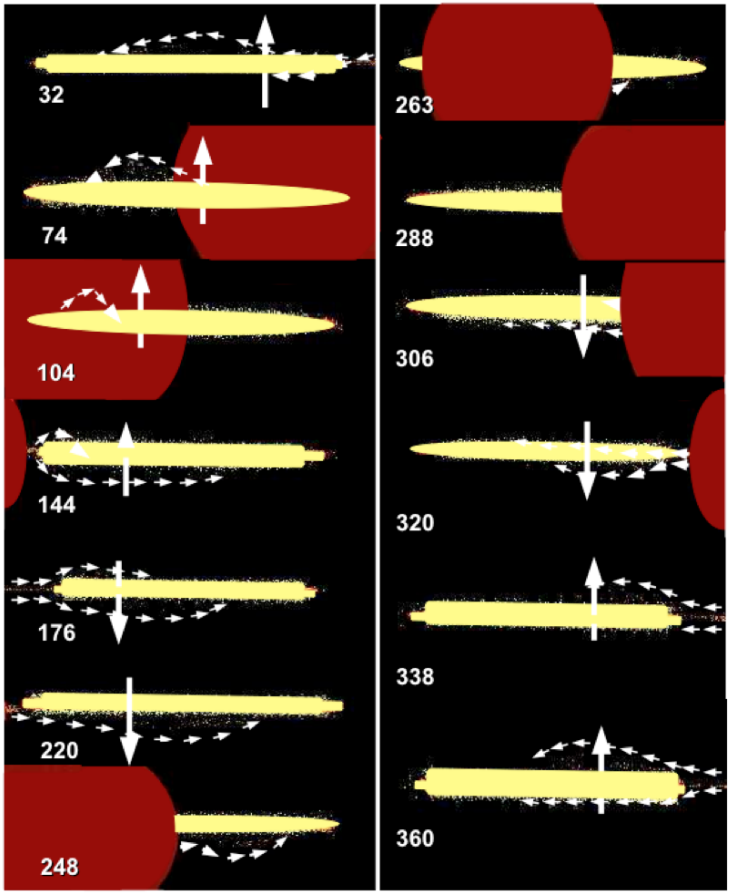


Montgomery (2012a ApJL)

# of Orbits~2700



Montgomery (2012-IAU)

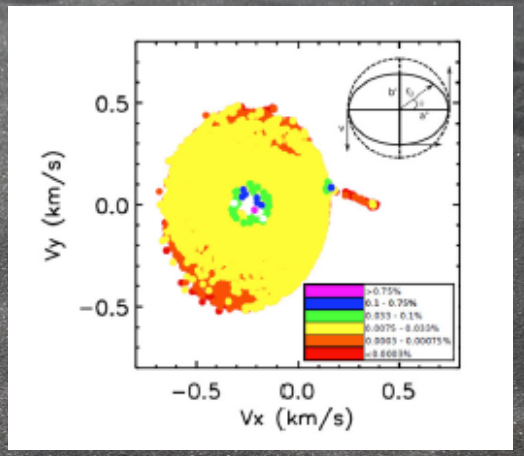


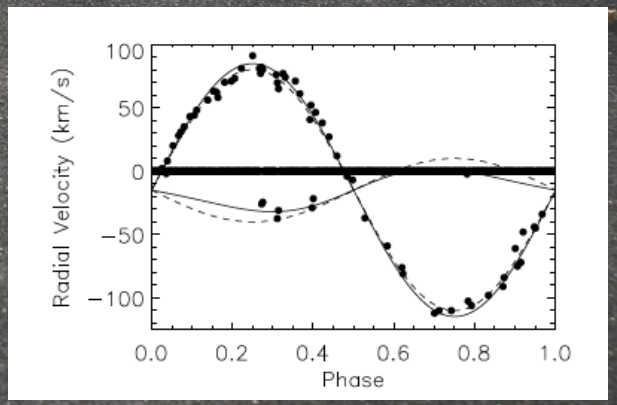
Montgomery (2012a)

(Current Studies) Radial Velocity

(Schwarz & Montgomery 2012 - IAU)

- q=0.4, M_1=0.8$M_\odot$ →→ untilted disk is elliptical
  - Colorize disk in v-space red=slow, violet=fast
- e.g. WW And (Siwak et al. 2012)
  - Dots: Hα emission line data
  - Dotted line – sin fit
  - Solid line – our analytical and numerical model
- Future: Apply technique (e.g., He II, RW Tri (Groot et al. 2004)
- In Review: 3D MHD HD Sims (Biskalo et al. 2012)





Summary and Other Conclusions

1. Accretion disks may tilt (depends on mass of disk and mass accretion rate)
2. If tilted, accretion disks may likely precess (for a variety of reasons)
3. Observables to confirm models: modulations in LCs, FFTs, RVs, Doppler tomography, etc.
4. Tilted disks are good tests of SPH codes simulating accreting compact binary systems.

montgomery_at_physics.ucf.edu