The Evolution of Cataclysmic Variables

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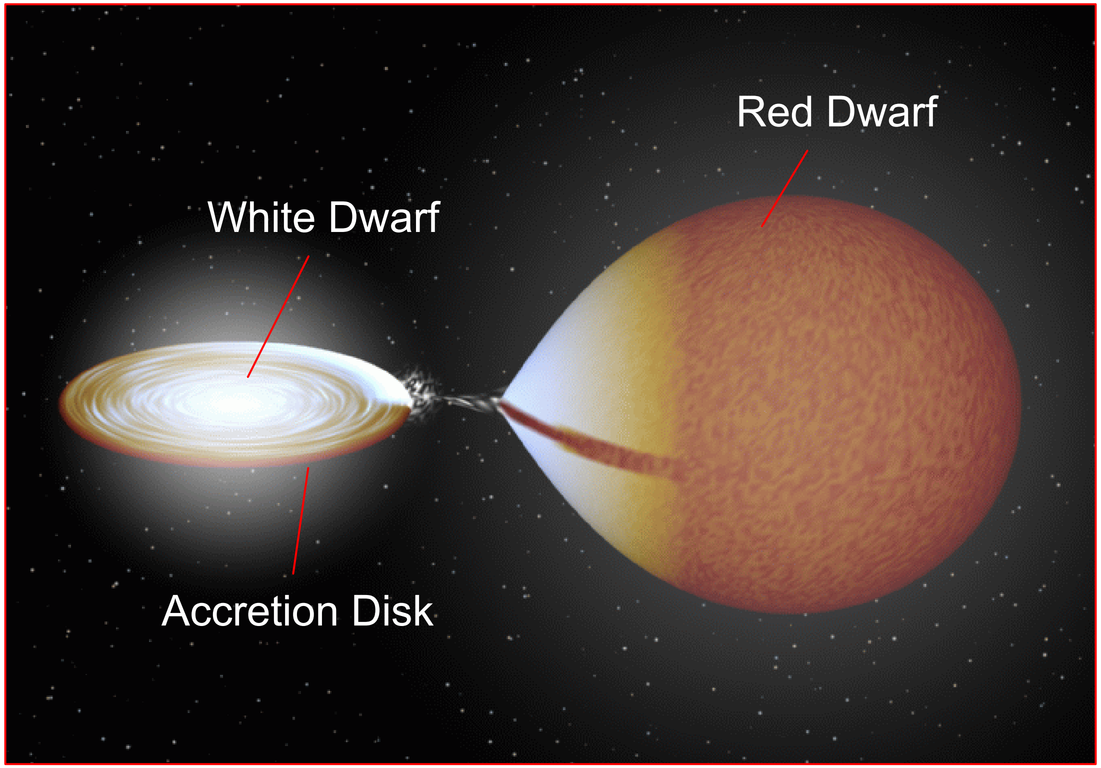
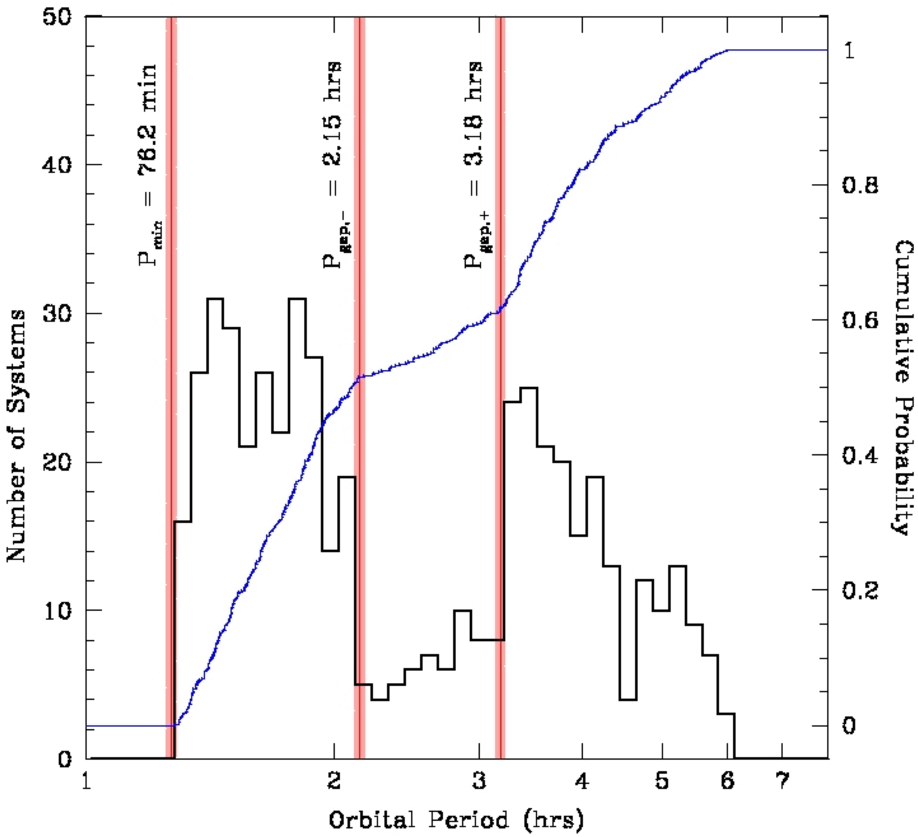
Cataclysmic Variables



Credit: Rob Hynes

- **White dwarf primary**
- **Main-sequence secondary**
- **Roche-lobe overflow**
- **Accretion usually via a disk**
- **75 mins < P_orb < 6 hrs**
- **SNIa progenitors**
- **Mass transfer and evolution driven by angular momentum losses**
- **Evolution is (initially) from long to short periods**

The Orbital Period Distribution and the Standard Model of CV Evolution

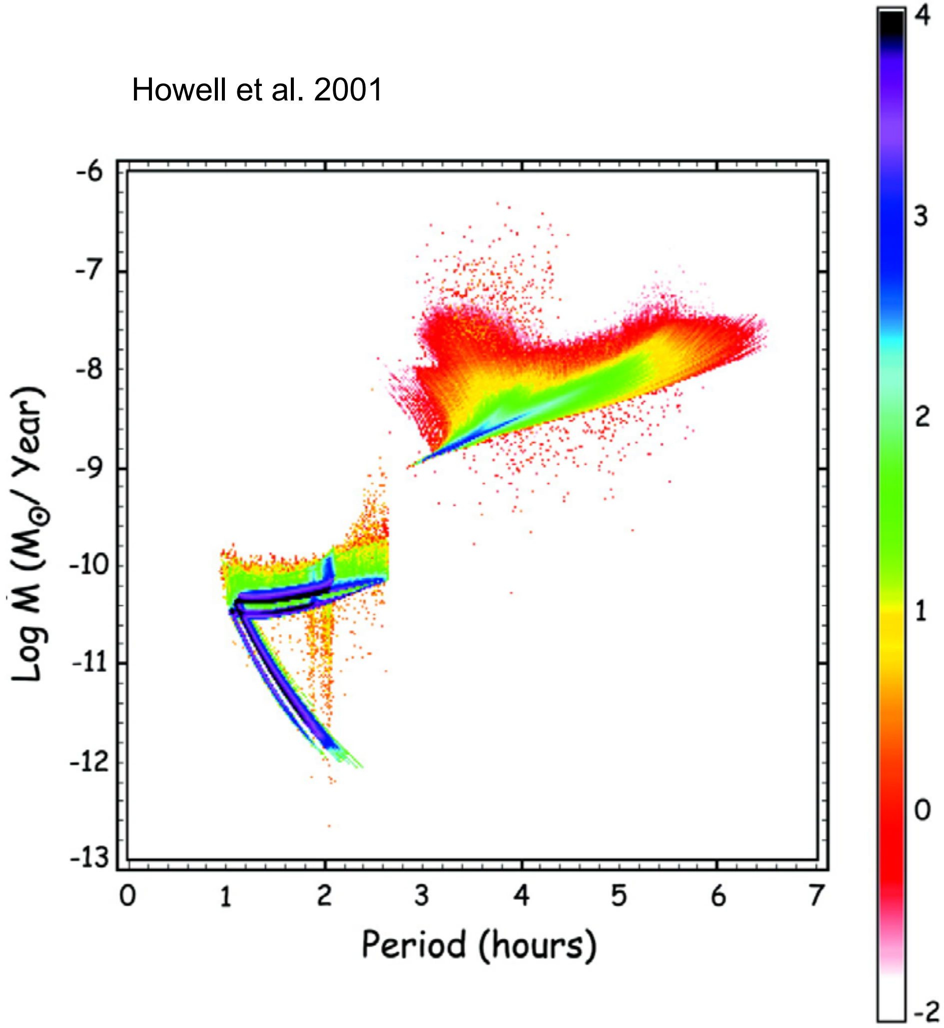


Knigge 2006

- Clear "Period gap" between 2-3 hrs
  - Corresponds to $M_2 \sim 0.2\text{-}0.3\ M_\odot$ where donors become fully convective
- Suggests a change in the dominant angular momentum loss mechanism:
  - Above the gap:
    - Magnetic Braking
    - Fast ---> High Mdot
  - Below the gap:
    - Gravitational Radiation
    - Slow ---> Low Mdot
- Minimum period corresponds to donor becoming a brown dwarf-like object
  - beyond this, P_orb increases again
- This is the "standard model" of CV evolution

The Galactic CV Population According to the Standard Model

Howell et al. 2001

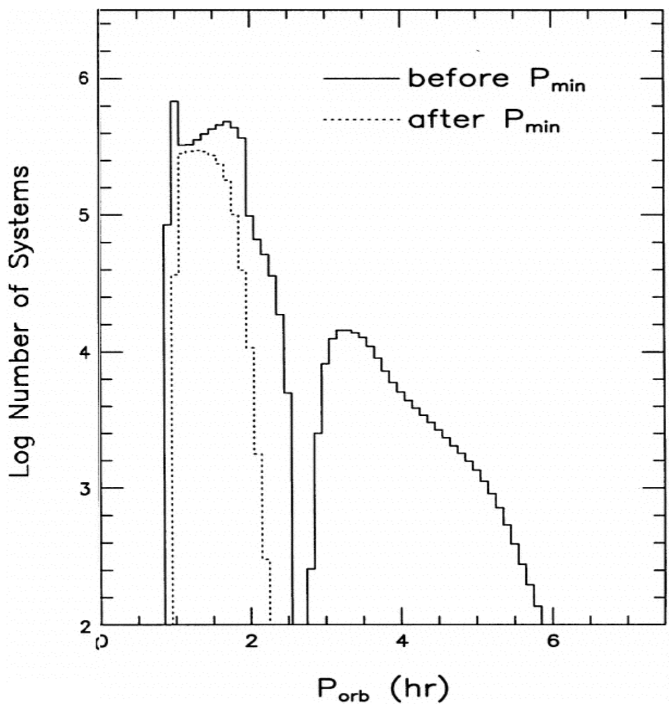


CV Population Synthesis

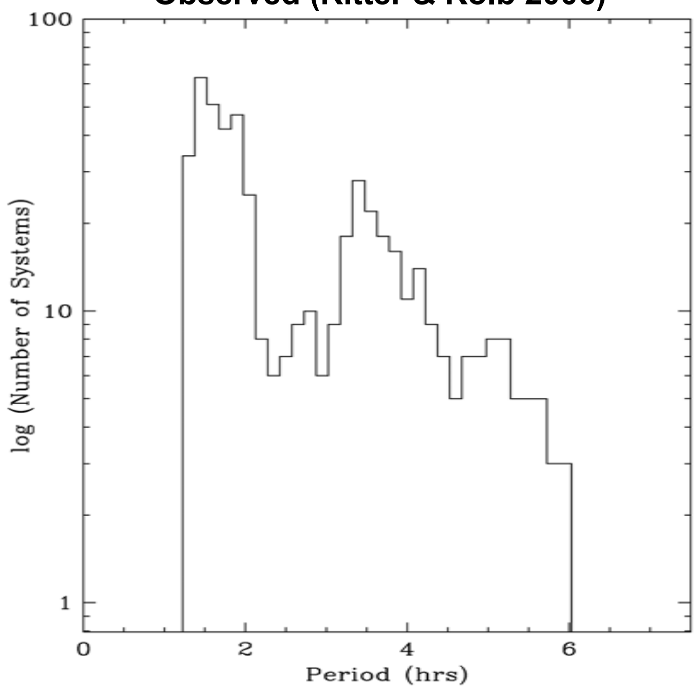
- Take a realistic population of MS-MS binaries
- Evolve through pre-CV phases
- Evolve through CV phase
- Predict properties of present day CV population
- Compare to observations

The Predicted Orbital Period Distribution

Predicted (Howell et al. 2001)



Observed (Ritter & Kolb 2006)

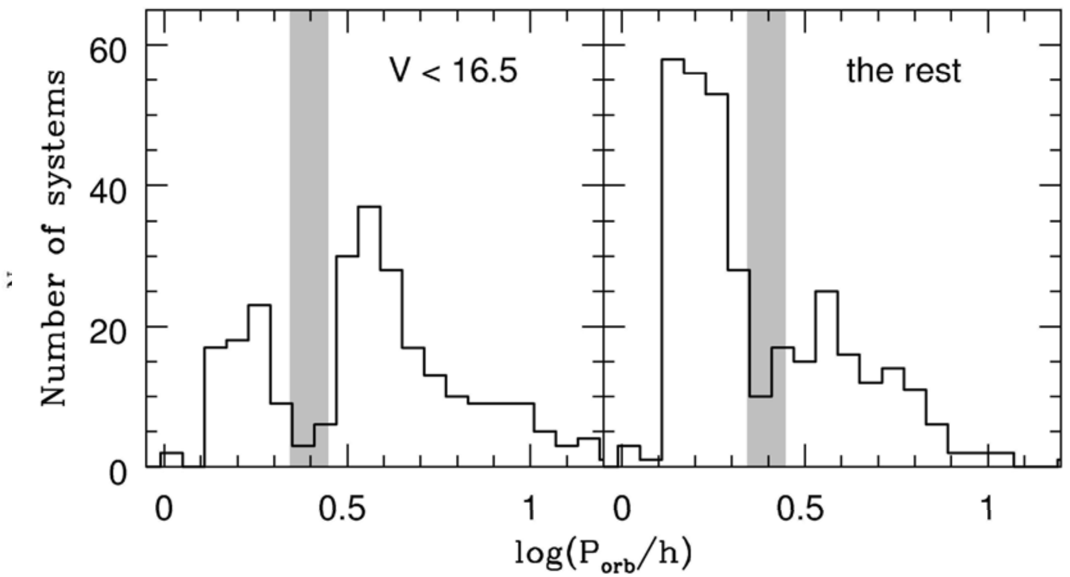


- 99% of all CVs should be below the gap
- 70% should already be “period bouncers”
- P_min = 65 mins

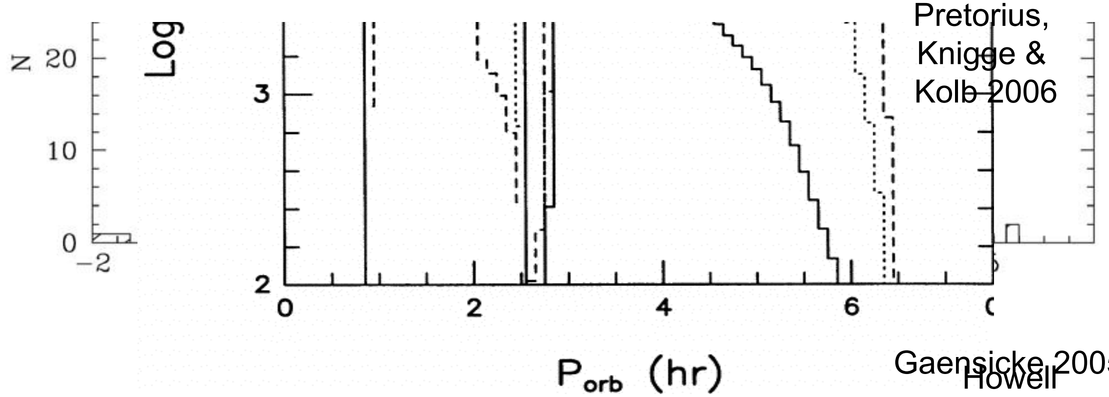
- 50% of known CVs are above the gap
- Almost no confirmed “period bouncers”
- P_min = 75 mins

So why is there even a debate?
Selection Effects!

- A simple magnitude cut has a dramatic effect on the observed distribution
- Each CV discovery method suffers from distinct selection biases
- A get-out clause for the standard model?
- ***We must finally face up to the selection effect problem!***



Pretorius, Knigge & Kolb 2006



Gaensicke 2005

Howell et al. 2001

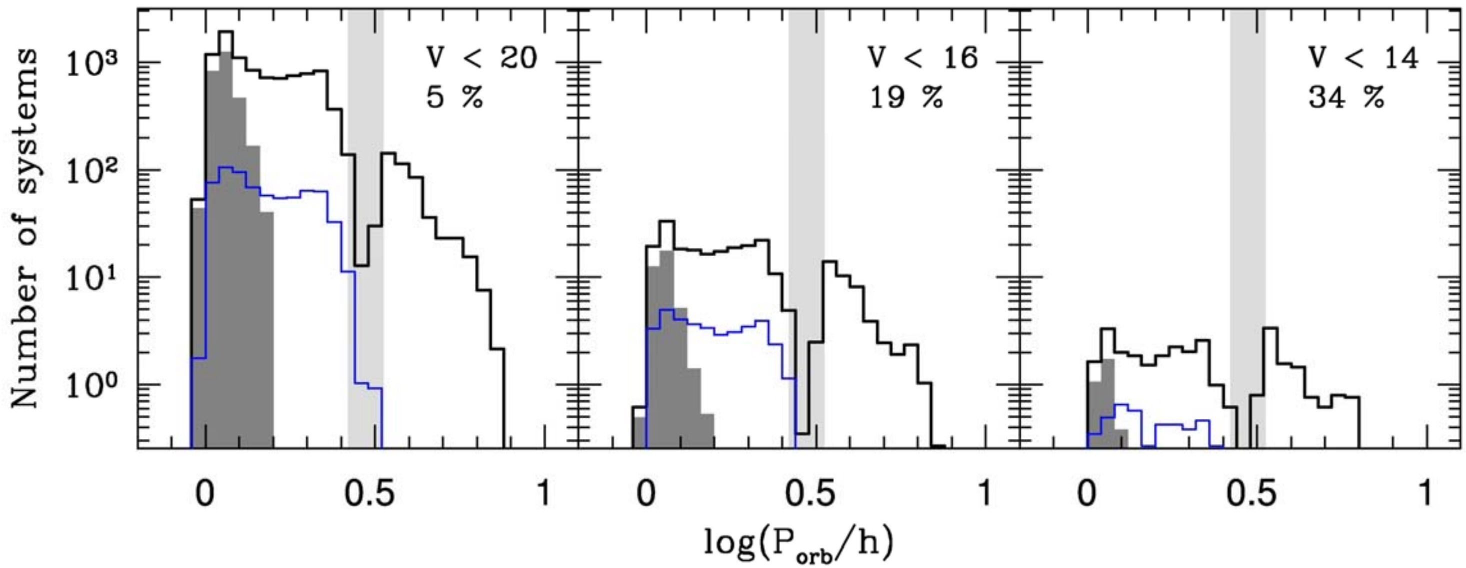
Dealing with Selection Effects:
A Brute-Force Monte Carlo Approach

Pretorius, Knigge & Kolb 2006

- Take the Galactic CV population predicted by a “standard-model” population synthesis calculation
- Create a simple, but realistic model of the Milky Way
- Distribute CVs appropriately within the model Galaxy
- Create a detailed model of the multi-component SED of each fake CV
  - WD (based on Townsley & Bildsten 2003)
  - Disk (Tylenda 1981)
  - Bright Spot (Blackbody)
  - Donor (Smith & Dhillon 1998, Knigge 2006)
- Work out extinction towards each fake CV
- Determine predicted fluxes/apparent magnitudes for each fake CV
- Apply *identical selection cuts* to the fake CVs as those affecting real sample(s)
- ***The resulting mock samples can be compared directly to the observed samples***

Dealing with Selection Effects: An Example

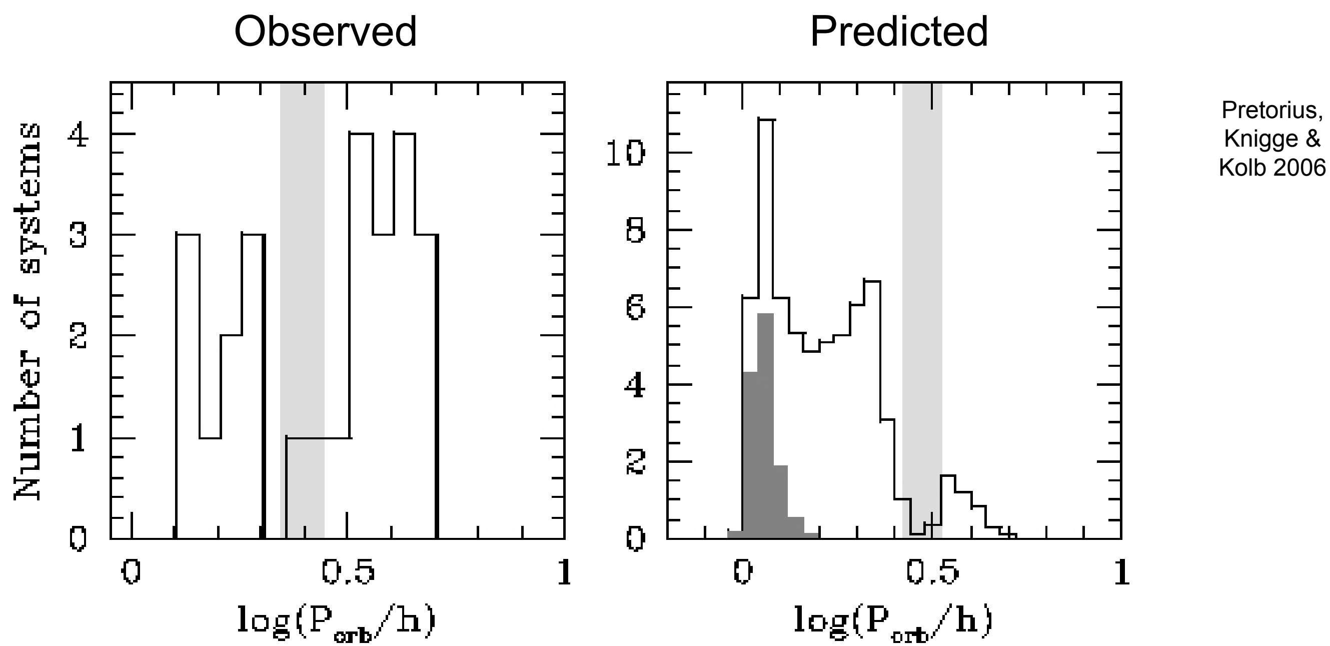
Pure Magnitude Cuts



Pretorius, Knigge & Kolb 2006

- Magnitude cuts have a strong effect on the observed P_orb distribution
- The brighter the cut, the higher the fraction of long-period CVs
- The "observed" fraction of ~50% corresponds to V_lim ~ 12
- But among all the CVs we know, only 12 are this bright -- all are long-period systems

Application to a Real Sample: CVs in the Palomar-Green Survey



Percentage of Long-Period CVs

- Predicted: 6.7% (2/27)
- Observed: 52% (14/27)

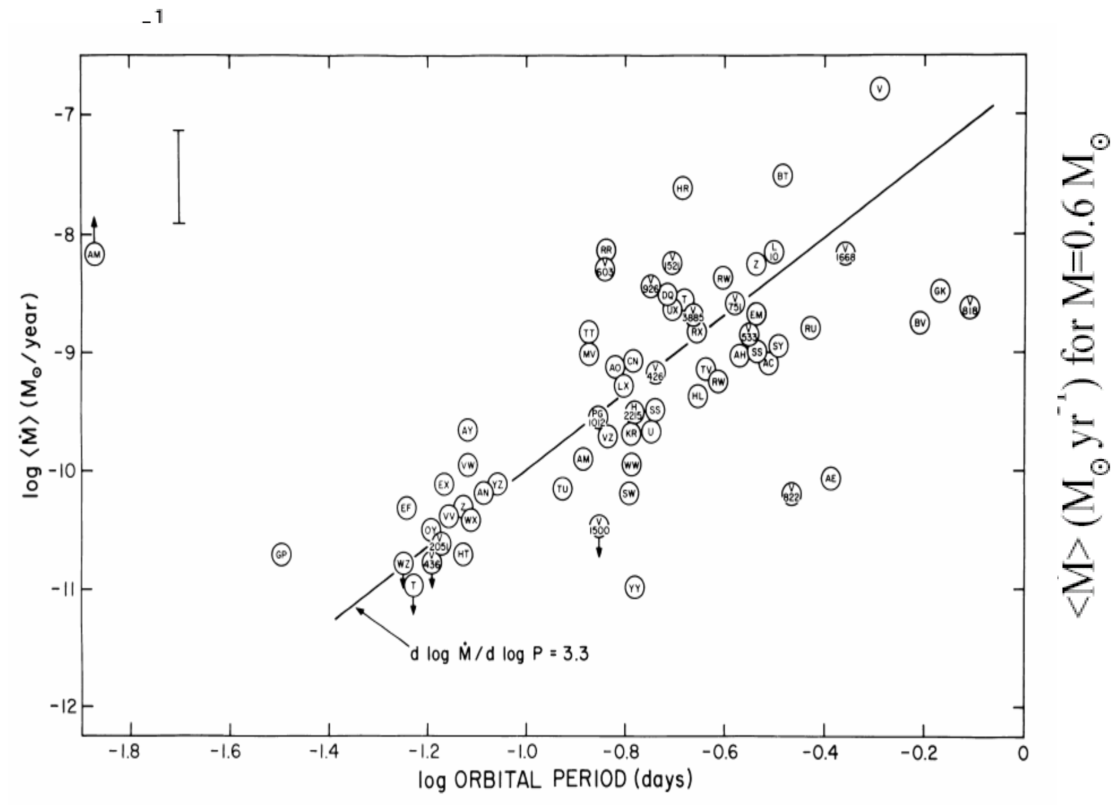
Percentage of Period Bouncers

- Predicted: 19% (5/27)
- Observed: 0% (0/27)

The standard model is ruled out by the data!

Beyond the Standard Model

- Wanted: An empirical Mdot/Jdot prescription for CVs!
- Existing attempts: estimate Mdot(P_{orb}) from
  - **accretion luminosity**
  - **WD temperature**
- So what's the problem?

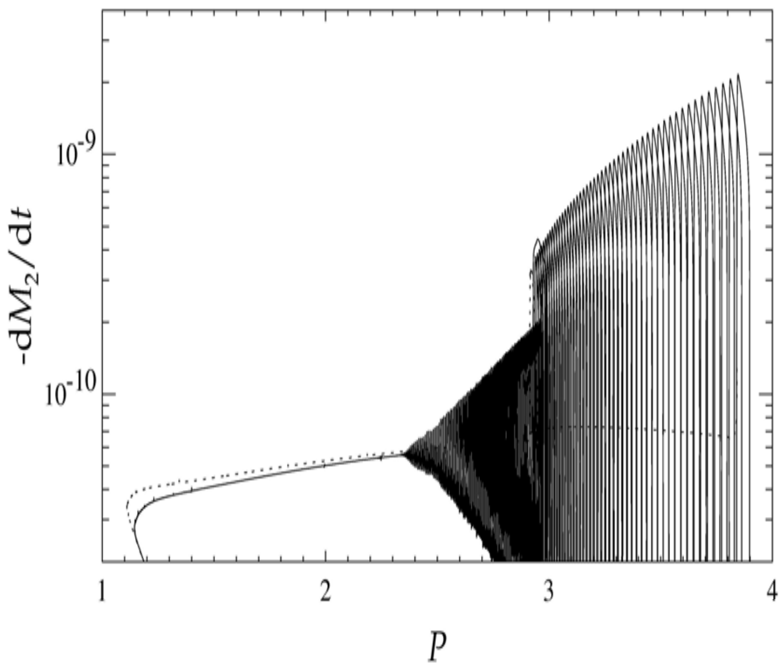


Townsley & Bildsten 2003
Patterson 1984

A Skeleton in the Closet?

- CVs may be subject to large mass-transfer rate fluctuations on unobservably long time-scales
  - Time-scale: ~100,000 yrs
  - Many/most/all observed CVs may be in an unrepresentative "high-state"
  - Most observed properties are then *<u>unreliable</u>* as tracers of evolution
  - This would affect all existing comparisons of observed and predicted CV properties (including ours!)

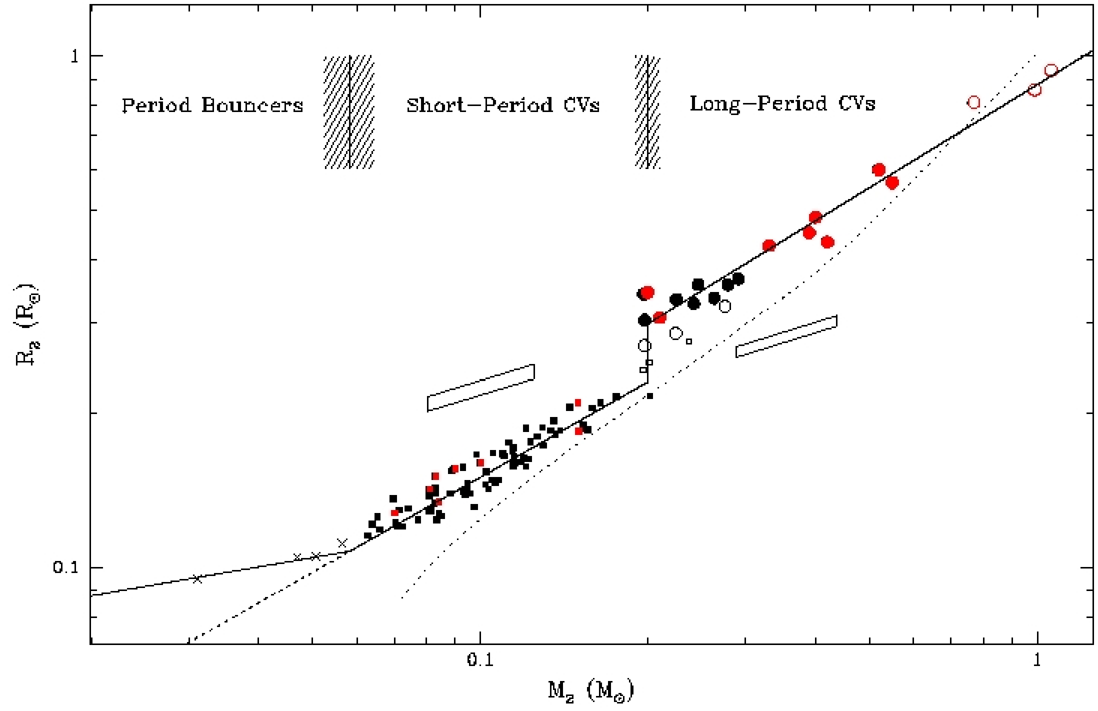
Buening & Ritter 2004



Towards A Truly Secular CV Evolution Track

- Is it even possible to construct a truly secular (long-term) CV evolution track empirically?
  - Yes, by focusing on the physical properties of the donor stars!
  - Mass loss drives CV donors slightly out of thermal equilibrium and makes them oversized compared to MS stars
  - Donors expand or contract on a thermal time-scale
  - Thermal-time scale ~ binary evolution time-scale
  - So donor properties should faithfully track the secular evolution

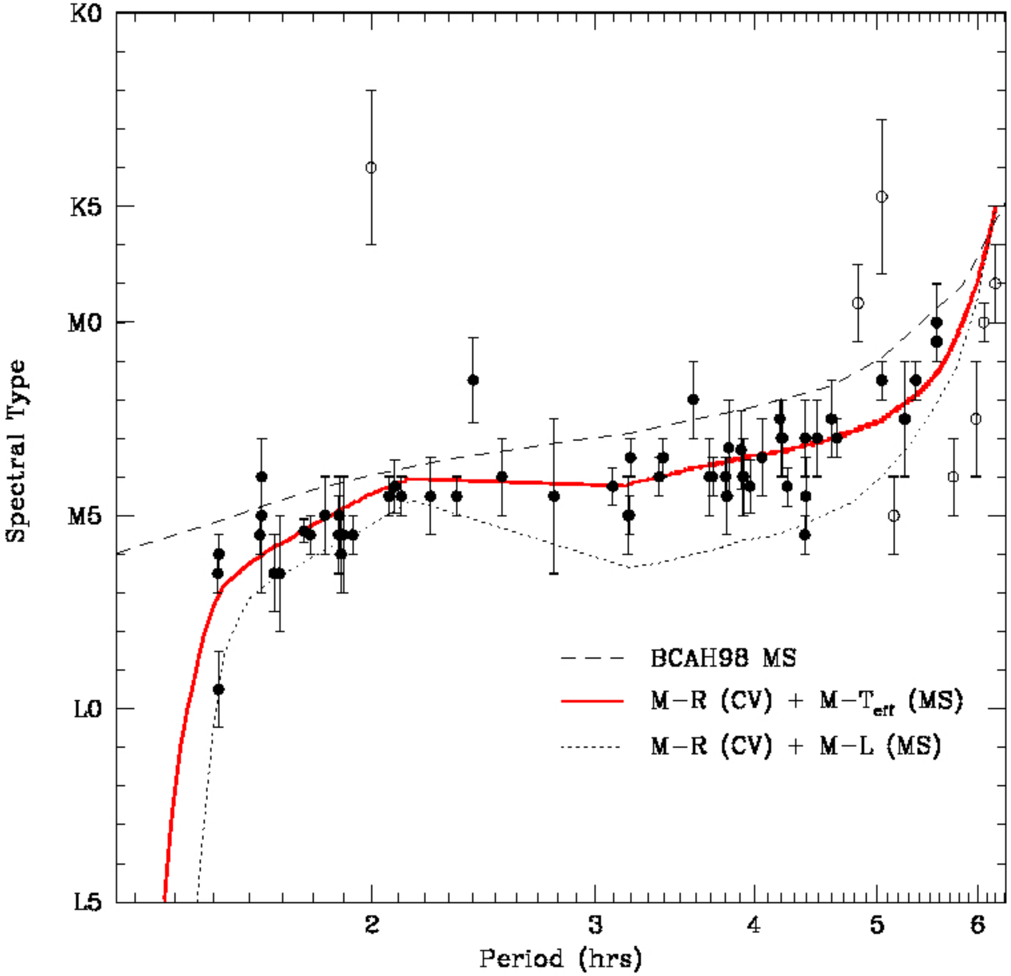
The Donor Mass-Radius Relation



Patterson et al. 2005
Knigge 2006

- Constructed from observations of eclipsing and "superhumping" CVs
- Donors are significantly larger than MS both above and below the gap
- Clear discontinuity at M_2 = 0.20 M_sun, separating long- and short-period CVs!
  - Direct evidence for disrupted angular momentum loss!

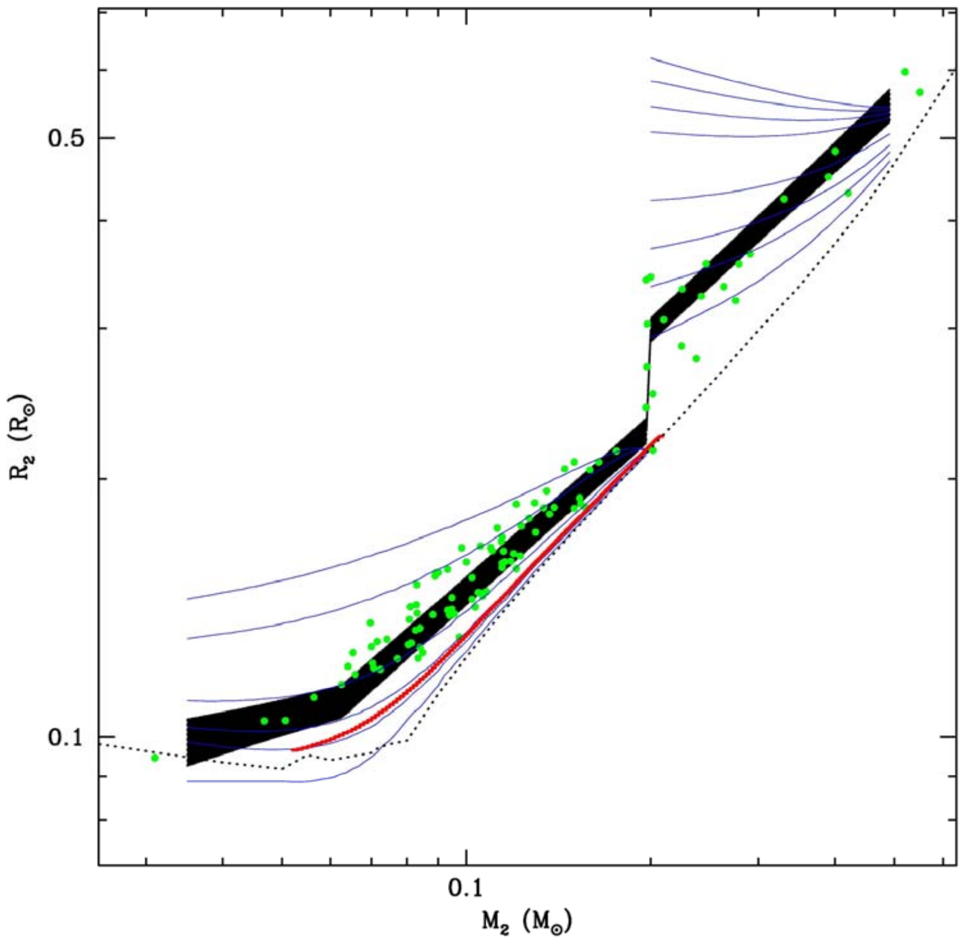
CV Donors vs Main Sequence Stars: Spectral Types



Knigge 2006

- CV donors have later SpTs than normal MS stars that are exactly consistent with their bigger-than-MS radii
- Confirms that donor radii are reliable
- Degree of radius expansion is a measure of Mdot
- Can use donor mass-radius relation to infer secular Mdot

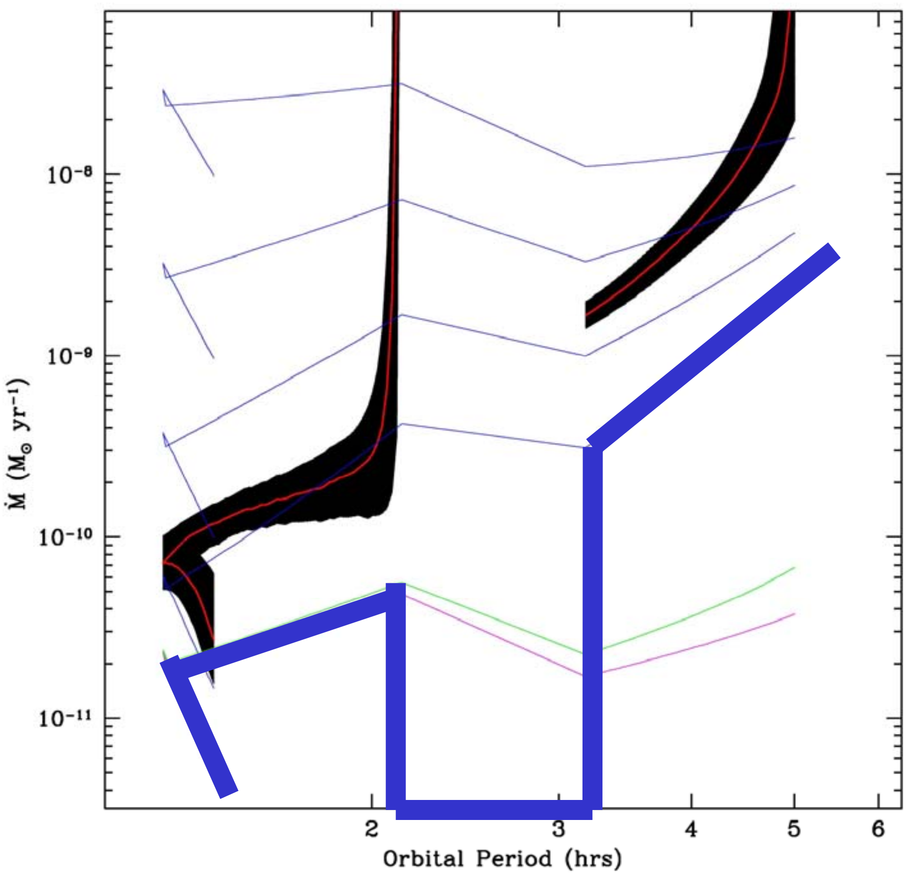
Secular Mass Transfer Rates from Donor Radii



Knigge, Patterson & Baraffe 2007

- Calculate a sequence of theoretical donor tracks, *each at fixed Mdot*
- Intersection of theoretical and observed track then provides an estimate of Mdot at that point

Results: The Secular CV Evolution Track



Knigge, Patterson
& Baraffe 2007

- Mass transfer rates are higher than "standard model" at all orbital periods, but especially below the gap
- Pure GR is insufficient to drive the mass transfer below the gap
- But clear evidence for AML "disruption" around the gap
- Perhaps not a total cessation of MB, but a reduction?
- May be associated with the donor's B-field switching modes as the radiative core is lost

Summary of Key Results

- Until recently, empirical tests of CV evolution scenarios have been plagued by severe selection effects
- We now have the tools to overcome this
  - Direct modelling of selection biases
  - Focus on donor properties
- Both methods agree that the standard model of CV evolution cannot be correct
- CV evolution is faster than predicted by the standard model, especially below the period gap
  - requires some form of AML in addition to GR below the gap

What Next?

- Construct a semi-empirical evolution scenario from donor properties
  - Is the resulting period distribution a better match to the observations?
- Wider implications
  - AML and MB are key to many other phases of binary (and single star!) evolution, including pre-CV phase
- Construct larger CV samples from deeper surveys with well-defined selection criteria!

IPHAS: An Hα Survey of the Northern Galactic Plane

Early Data Release

Point Source Hα Excess Catalogue

Both to be released in the next few weeks!

www.iphas.org

Drew et al. 2005; Witham, Knigge et al. 2005, 2007