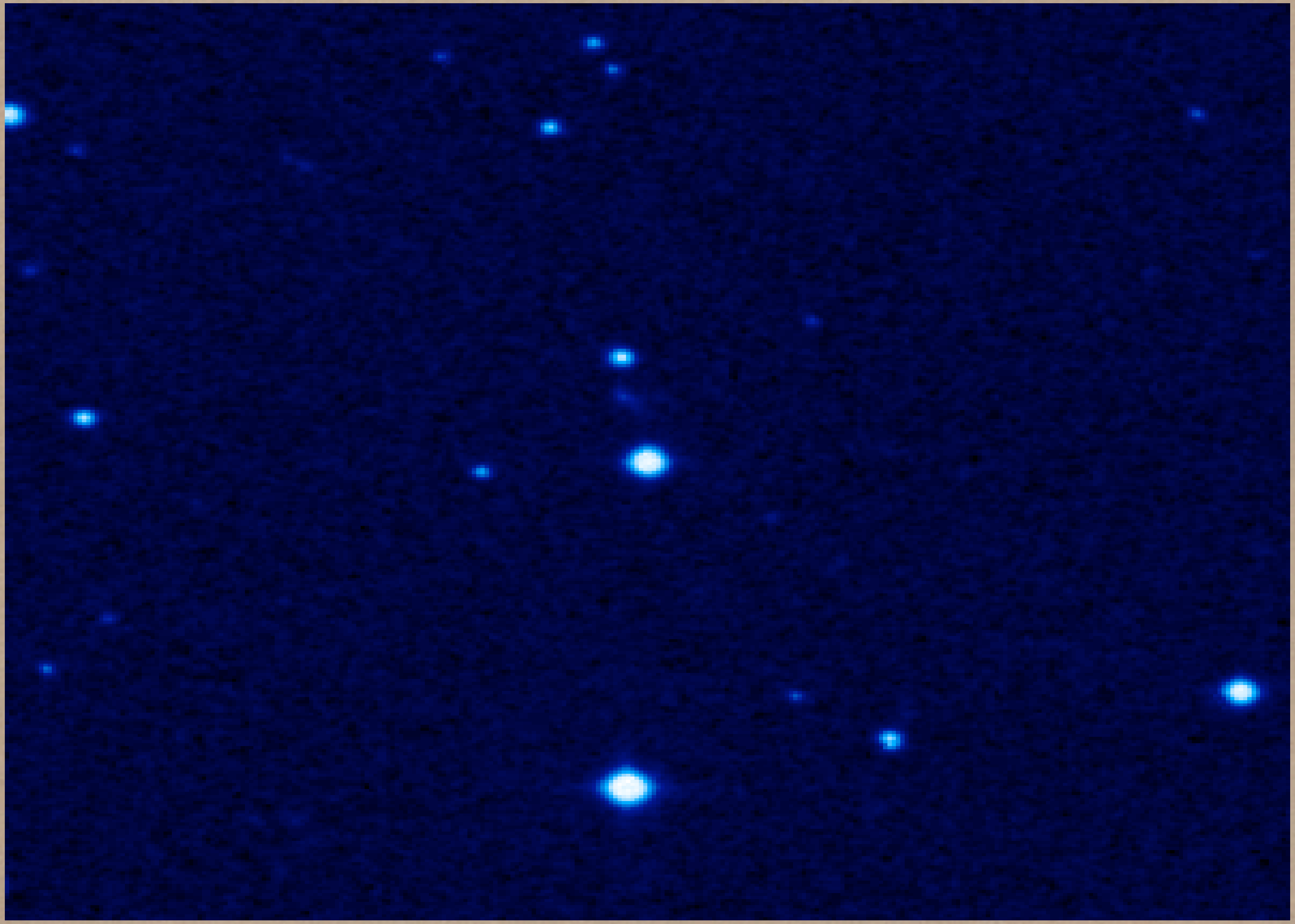
The AM CVn Binaries: An Overview

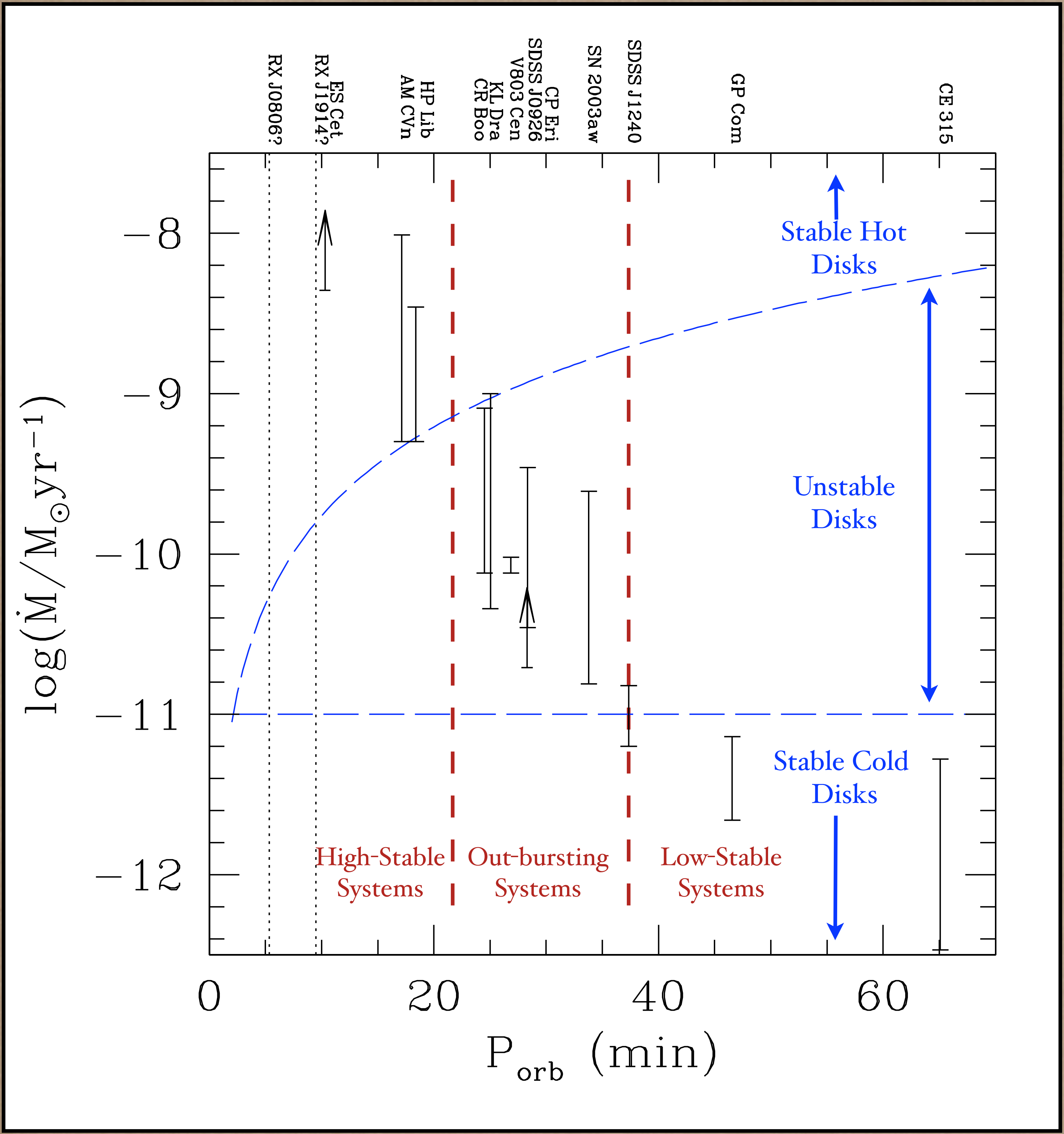


Christopher Deloye
(Northwestern University)

Introduction and Outline

- Focus of Talk: What can we learn from the observed AM CVn population
  - about the binary evolution processes that set the initial parameters of potential AM CVn systems?
  - about the physics that set the outcome of starting mass transfer as a function of these initial parameters?
- Outline:
  - The AM CVn Binaries:
    - Basic Properties.
    - Formation channels.
  - Answering the above questions:
    - Diagnostics developed from theory.
    - The developing observational picture.
    - Conclusions and a look forward.

AM CVn Stars: The Basic Picture

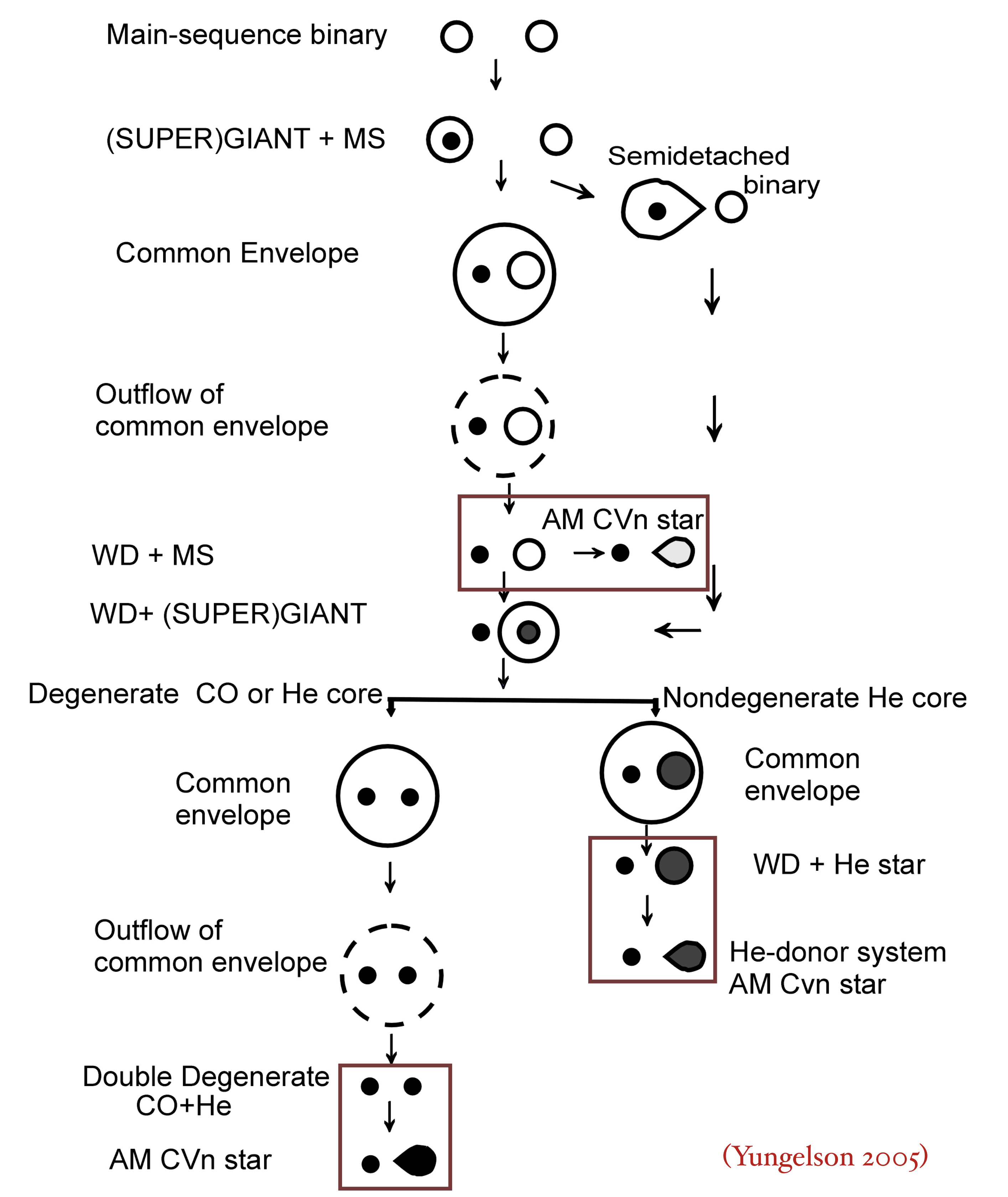


(Mass transfer ranges from theory based on orbital period and mass ratios quoted in Deloye et al., 2005.)

- Binary systems (Paczyński 1967, Faulkner et al 1972):
  - C/O or He WD accretor .
  - He-dominated compact donor.
- Angular momentum losses from gravity wave (GW) emission drives the orbital evolution.
- Photometric behavior correlates with period via mass transfer rate as explained by He-disk instability model (Smak 1983, Tsugawa & Osaki 1997).
  - High and low mass transfer rates lead to stable hot/cold disks.
  - Intermediate rates lead to disks that produce the He DNO systems.
- Optical light dominated by (Bildsten et al. 2006):
  - Disk in high-state and DNO systems in out-burst.
  - Reheated accretor in low state and quiescent DNO systems.

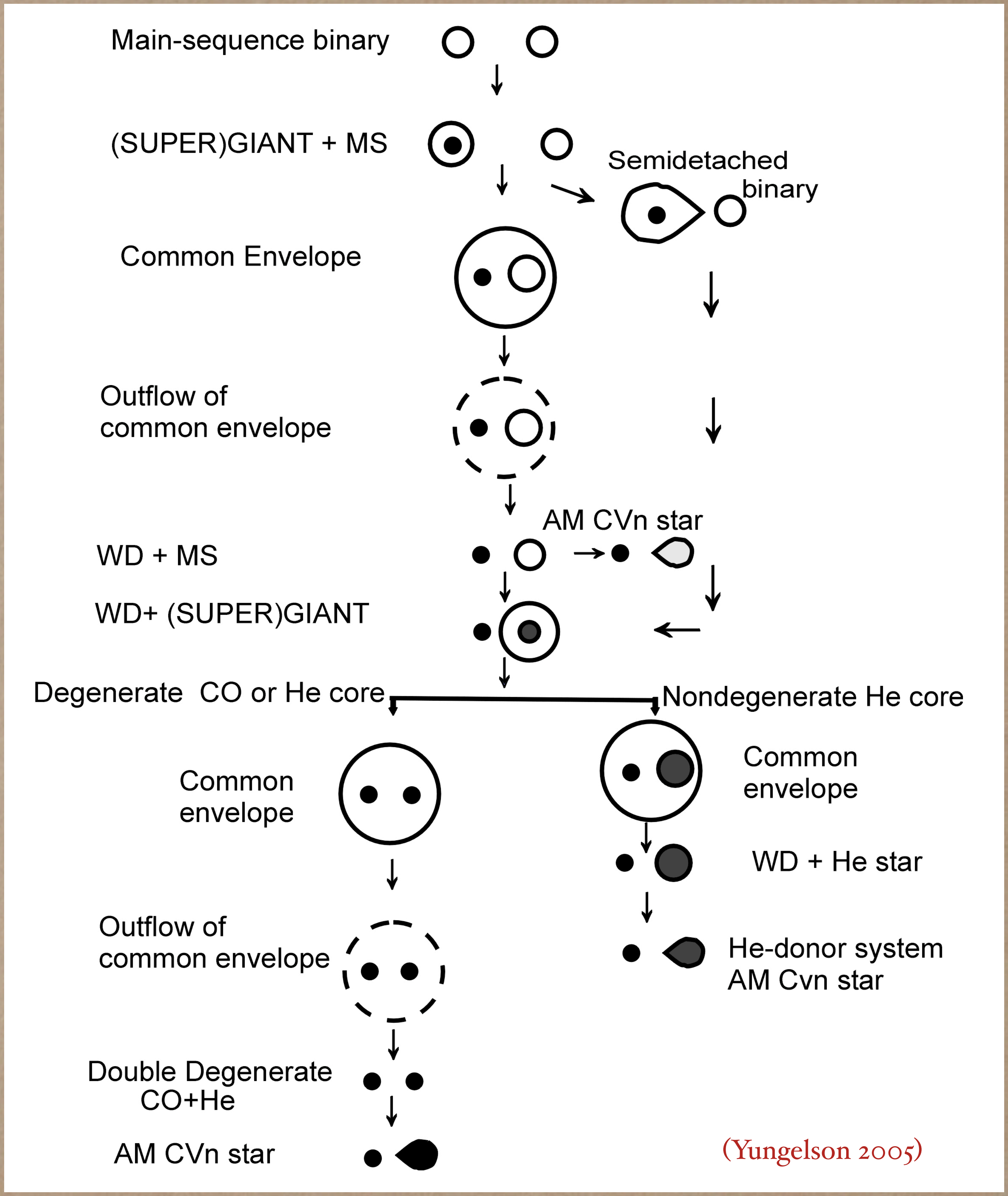
AM CVn Binaries: Formation Channels

- 3 possible formation channels:
  - Single CE → WD+Evolved-MS
    (CV channel, Podsiadlowski et al. 2003)
  - Double CE→ WD+"WD"
    (WD channel, Nelemans et al. 2001)
  - Double CE→WD+He star
    (He-star channel, Nelemans et al. 2001)
- Donor properties expected to vary within each channel, e.g.:
  - CV channel: H content, minimum orbital period.
  - WD channel: donor entropy, contact orbital period.
  - He-star channel: core He vs. C/O fractions.
- Only CV and WD channels have been modeled in detail [Podsiadlowski et al. 2003, Deloye et al. 2005, 2007(*submitted*)].
- Formation channel influences contact $P_{\rm orb}$ and mass-transfer rate evolution.



(Yungelson 2005)

What Can the Observed AM CVn Population Tell Us?



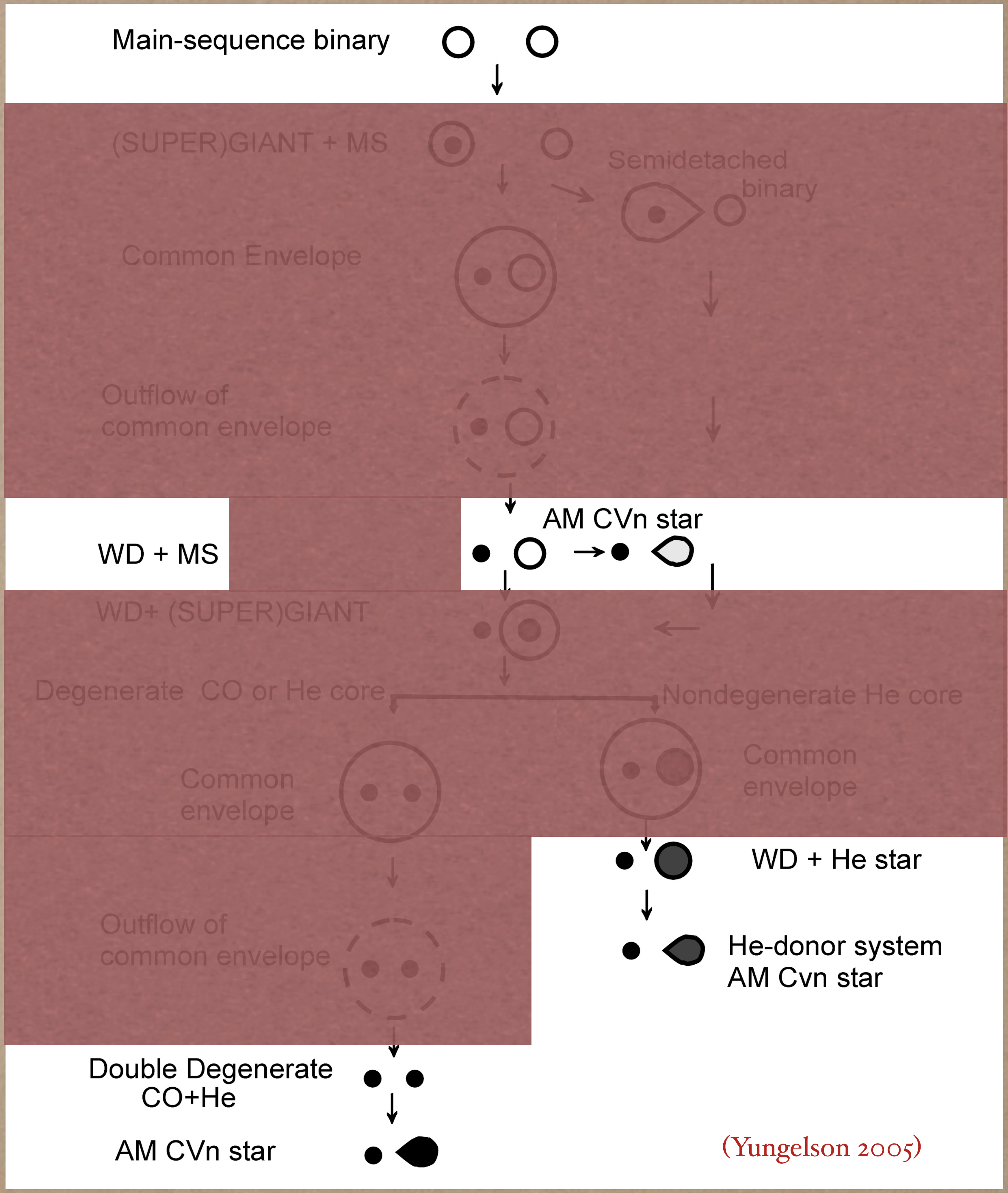
What Can the Observed AM CVn Population Tell Us?

Primordial Binary Parameters:
(M_1', M_2', a')

Binary Evolution Processes

Binary Parameters at Contact:
$[M_{1,i}, M_{2,i}, R_{2,i}, X_{2,i}]$

Post-Contact Outcomes



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Binary Evolution

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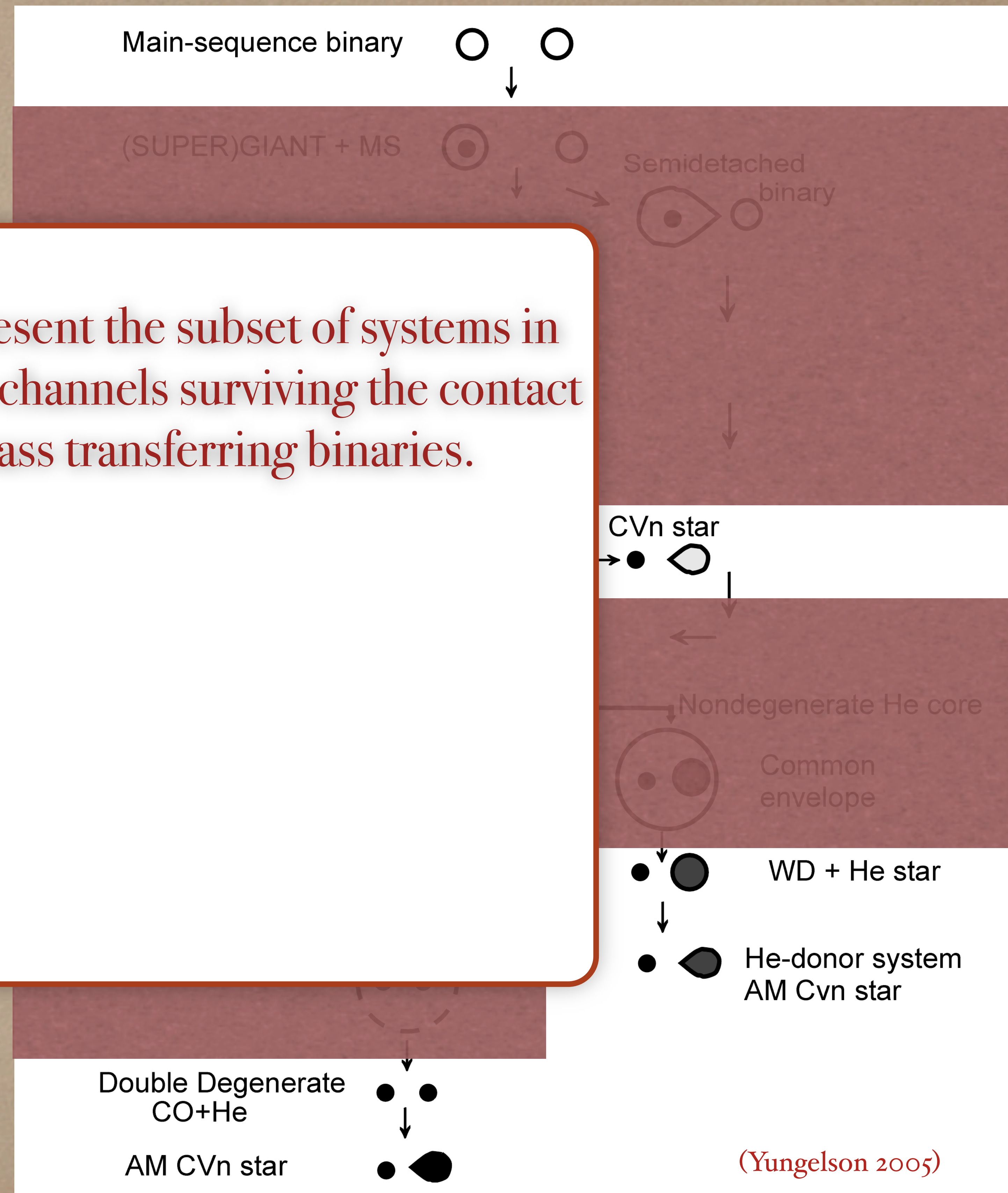
Post-Contact Outcomes

AM CVns represent the subset of systems in these formation channels surviving the contact phase as mass transferring binaries.



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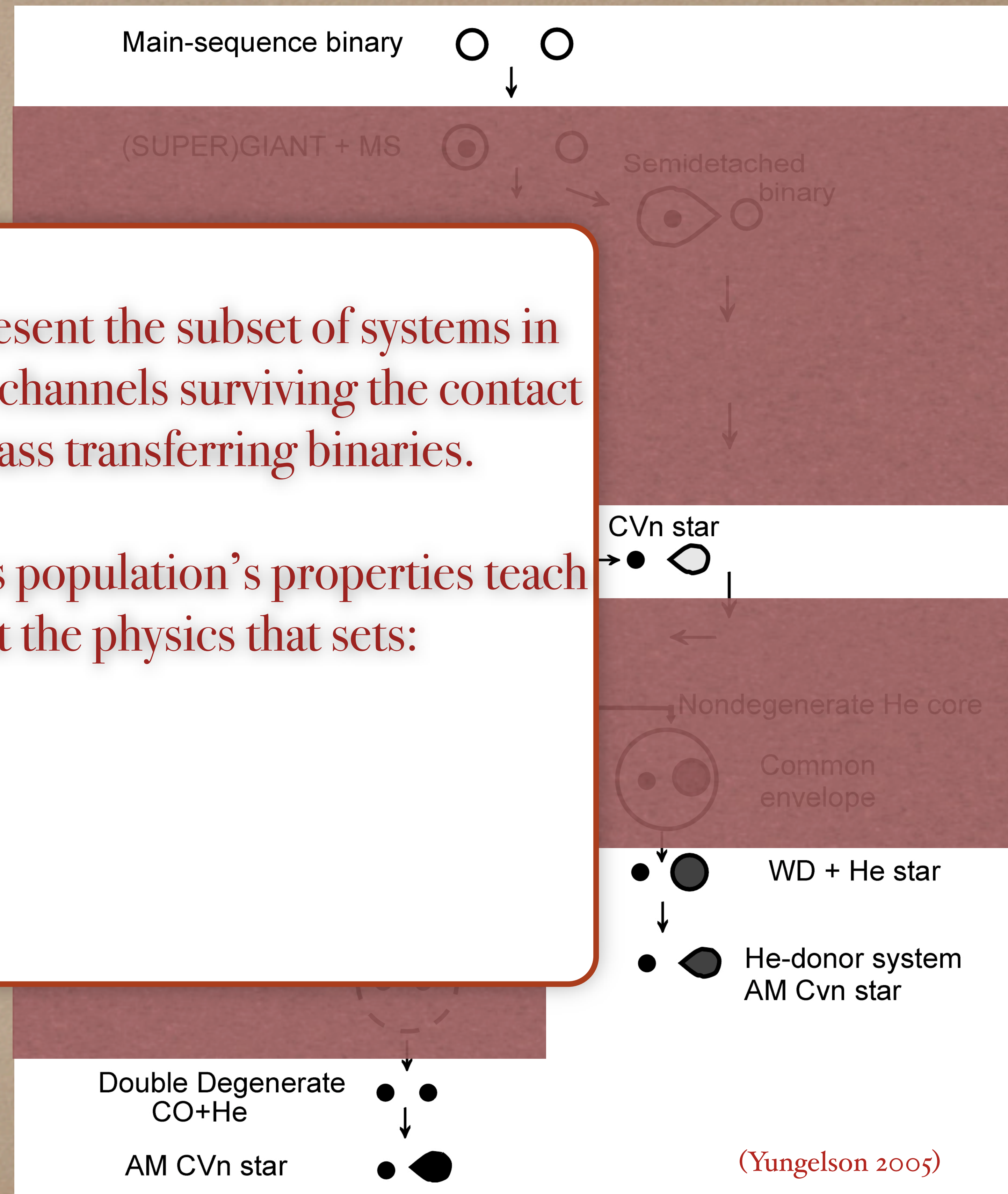

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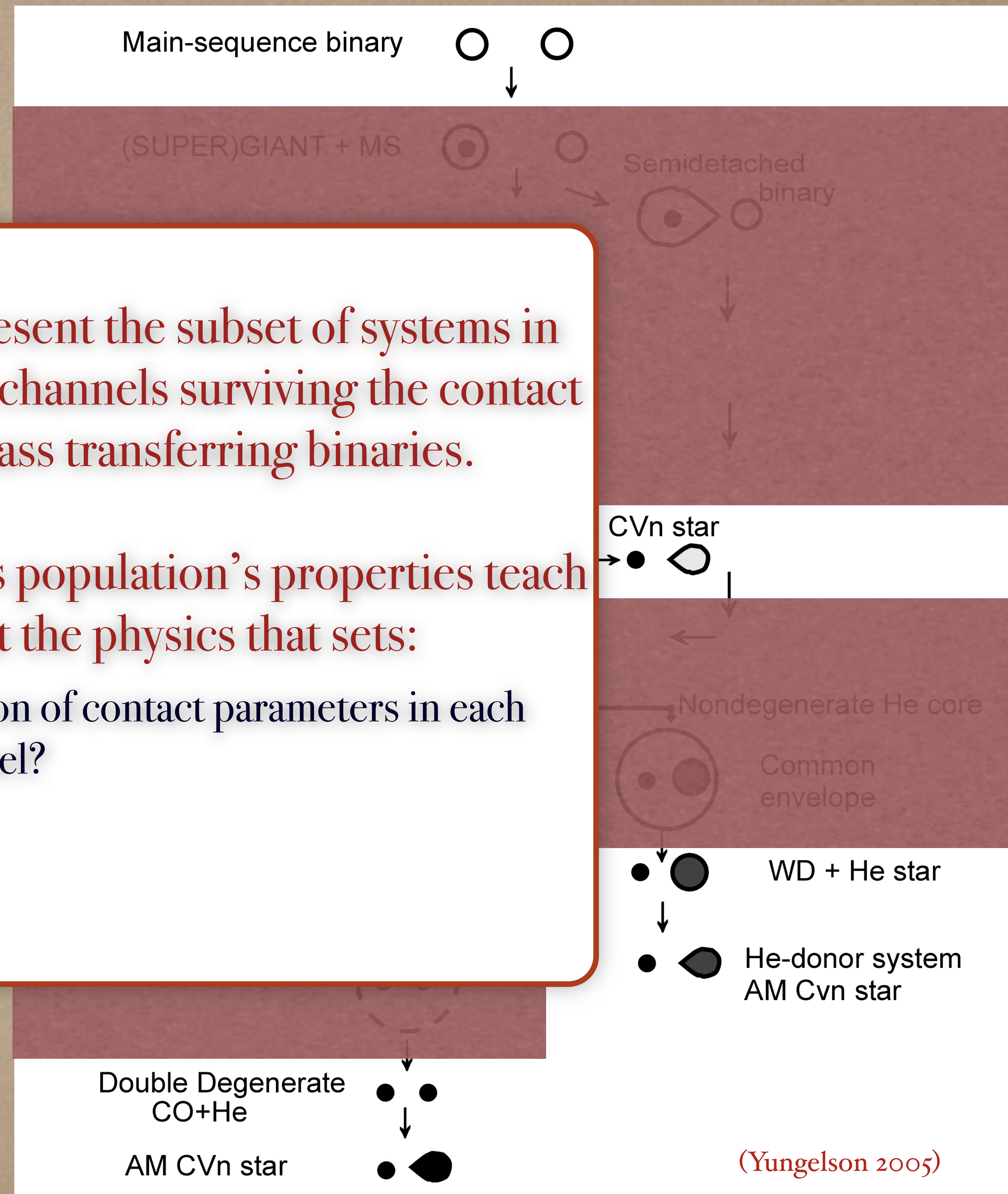

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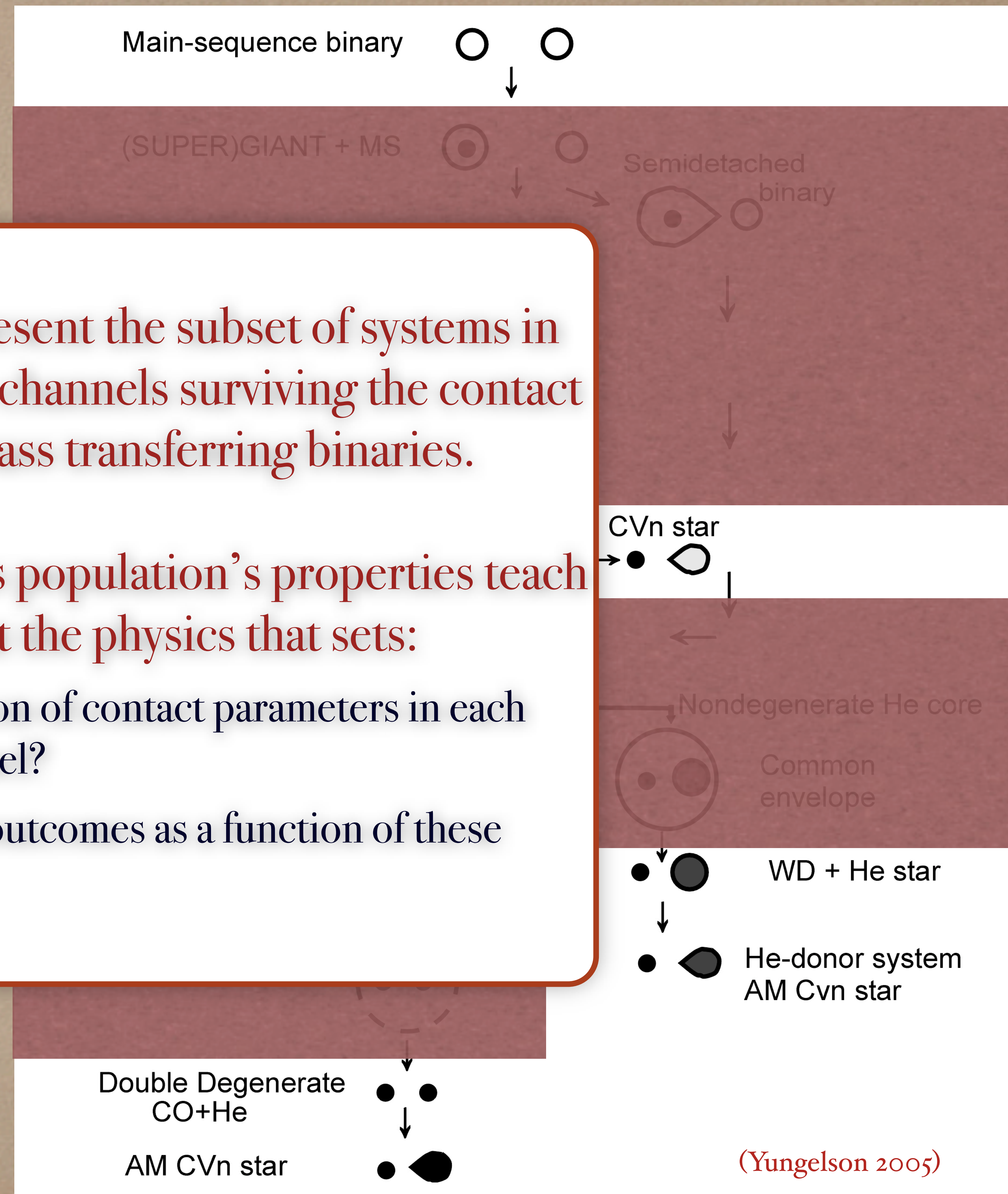
➠What can this population's properties teach us about the physics that sets:

1. The distribution of contact parameters in each formation channel?

2. Post-contact outcomes as a function of these parameters?



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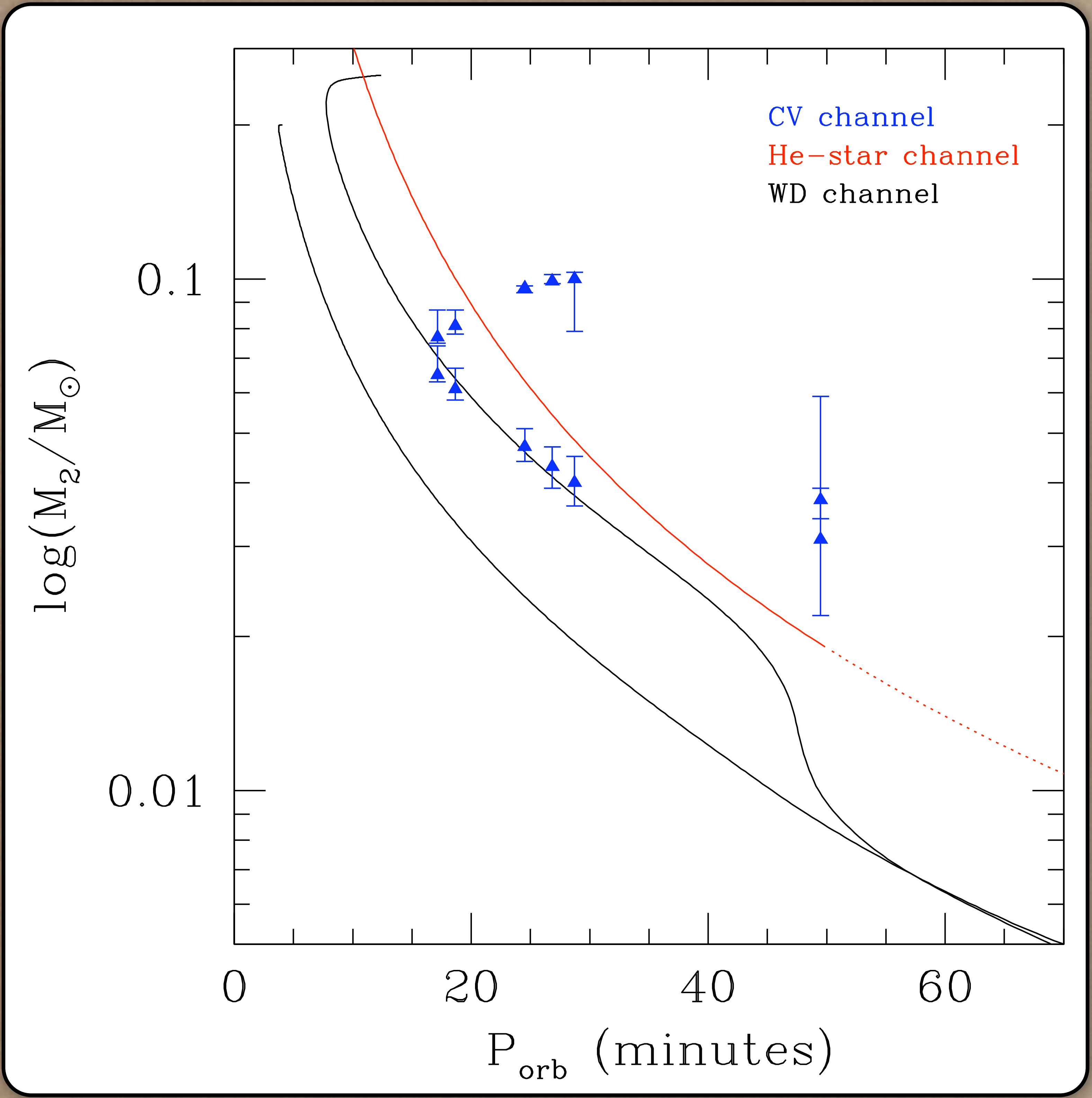
Diagnostics I: $M_2(P_{orb})$ Relation



- Equivalent to $M_2(R_2)$:
$$P_{\rm orb} \approx 9\,{\rm hr} \left(\frac{R_2}{R_\odot}\right)^{3/2} \left(\frac{M_2}{M_\odot}\right)^{-1/2}$$
- Directly constrains donor's entropy :
    - In WD/He-star channels, this reflects initial data out to $P_{\rm orb} \approx$ 45-55 minutes (Deloye et al. 2007).
- Determinations:
    - "Directly" (e.g., from eclipse light-curves).
    - Indirectly; e.g., from secular mass transfer rate:.
$$\frac{\dot{M}_2}{M_2} = \frac{2\dot{J}/J}{\xi_2 + 2\left(\frac{5}{6} - q\right)}$$
$$\xi_2 = \frac{d\ln R_2}{d\ln M_2} \qquad q = \frac{M_2}{M_1}$$
- Overlap between CV channel and WD/He-star channels.

(Nelamans et al. 2001, Podsiadlowski et al. 2003, Deloye et al. 2007)

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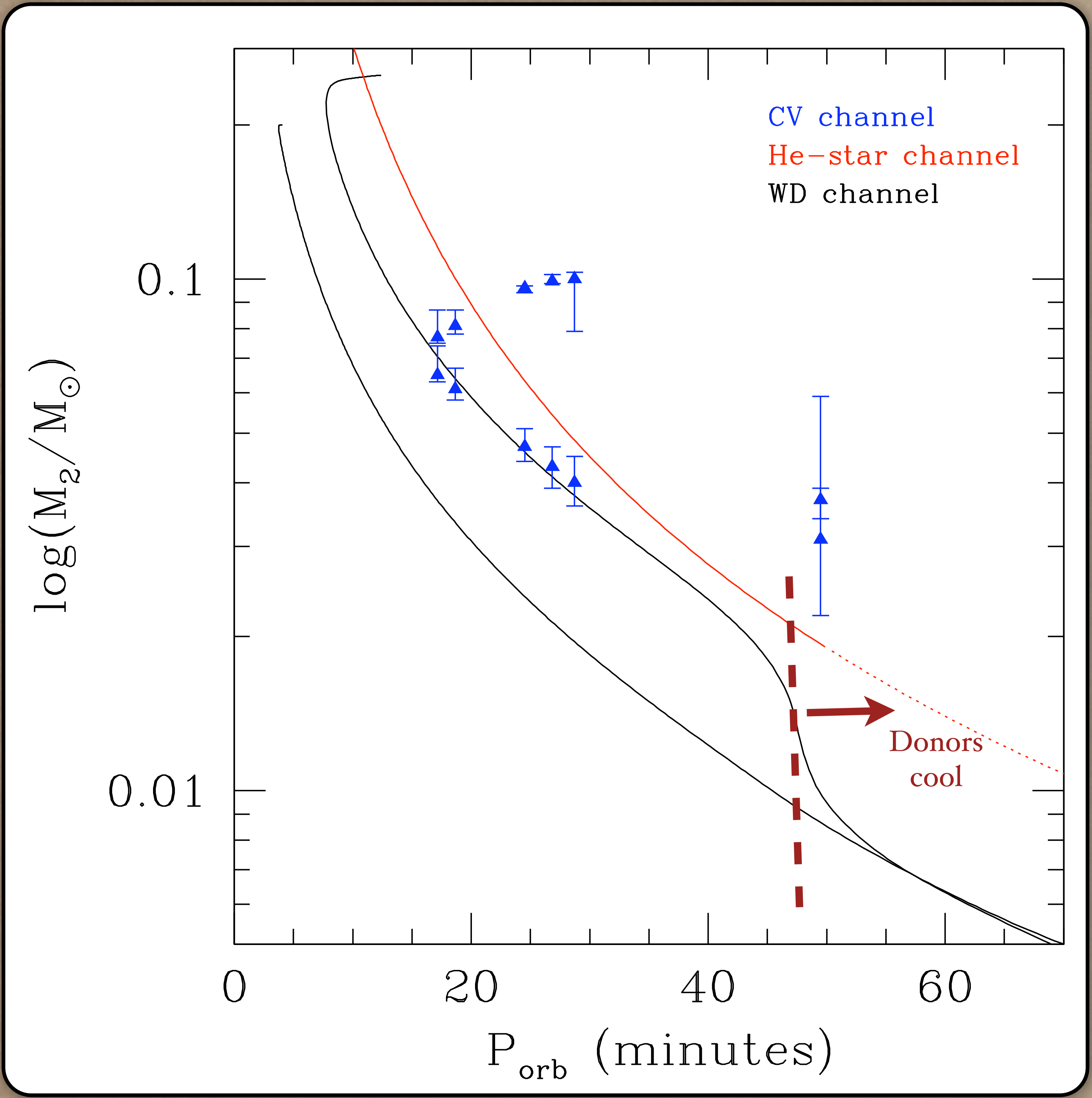

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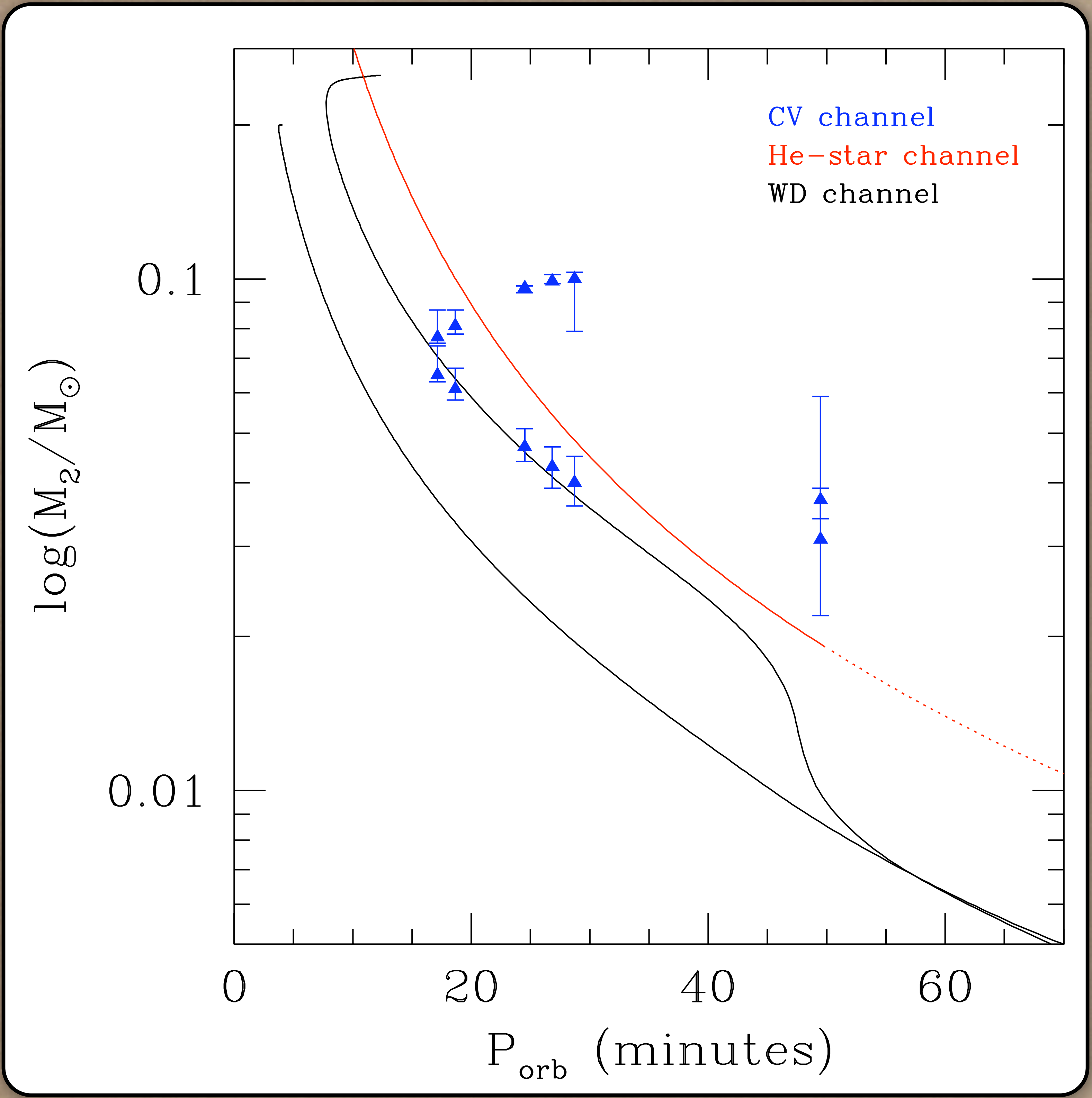

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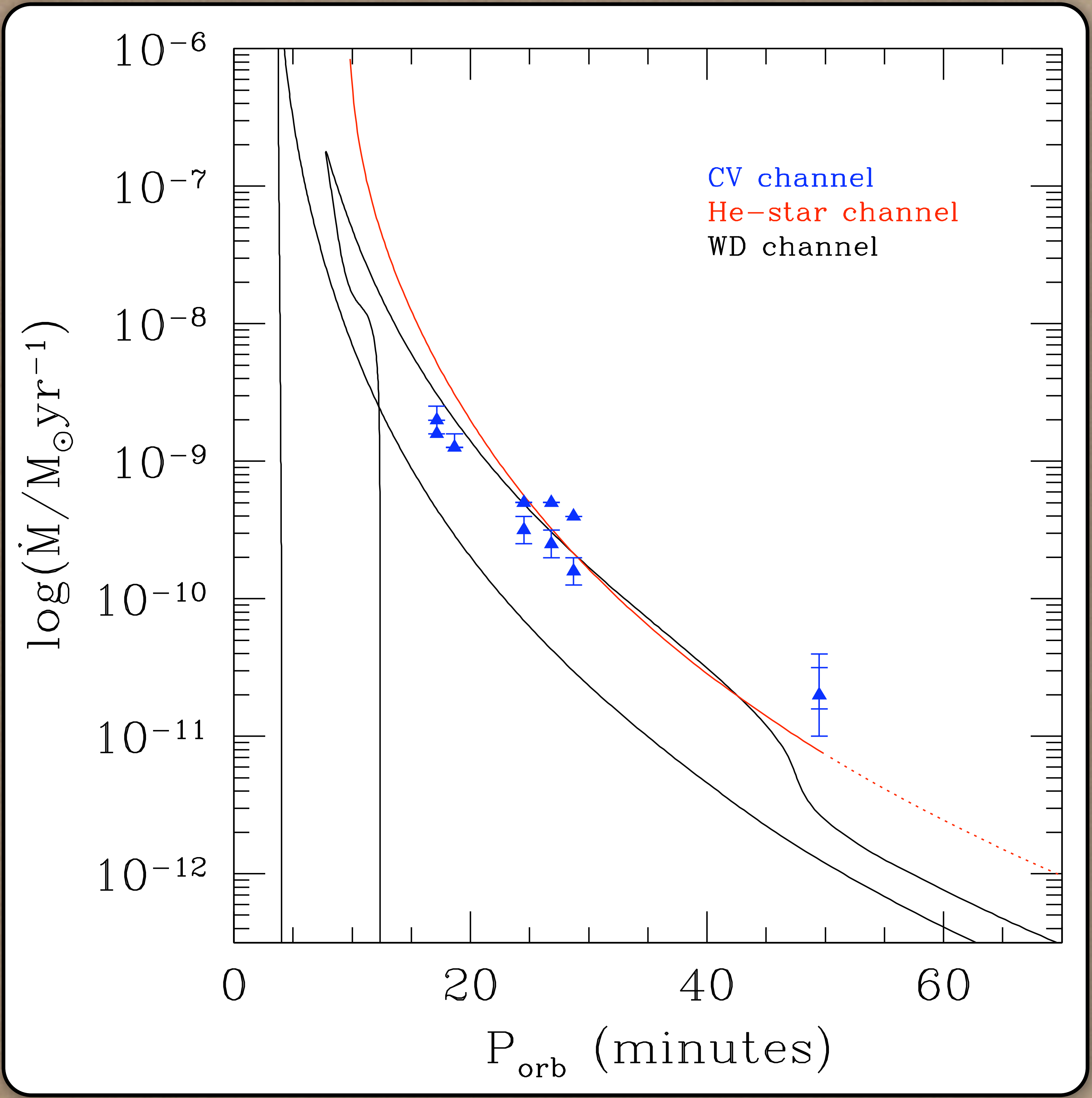

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Diagnostics II: H, He, C, N, and O Abundance Patterns

- CV channel below $P_{orb} \approx 30$ minutes (Podsiadlowski et al. 2003):
  - Inwardly evolving systems have H mass fraction, $X \approx 0.01\text{-}0.22$.
  - Outwardly evolving systems, $X \approx 0.0\text{-}0.04$.
  - Typical X values decrease with decreasing minimum P_{orb}.
- He-star channel:
  - No H post-P_{orb} minimum.
  - Expect variations in He to C/O ratios depending on extent of He burning before contact (Nelemans et al. 2001, Savonije et al. 1986, Tutukov & Fedorova1989).
  - About 50% of systems in this channel make contact in <10% of He-burning lifetime; 80% in <40% of He-burning lifetime (Nelemans et al. 2001).
  - Ratio of N to C/O should be down from expectations for CNO-process ashes.
- WD channel:
  - No H post-P_{orb} minimum.
  - He burning never gets underway, so CNO-process ashes: He dominated, N overabundant compared to C and O.

Observational Data I: SDSS J0926+3624, an Eclipsing AM CVn

Discovered by Anderson et al. (2005)

Eclipse light-curve fits
(Marsh et al. 2006) :

$$q = 0.035 \pm 0.002$$
$$M_1 = 0.84 \pm 0.05 M_\odot$$
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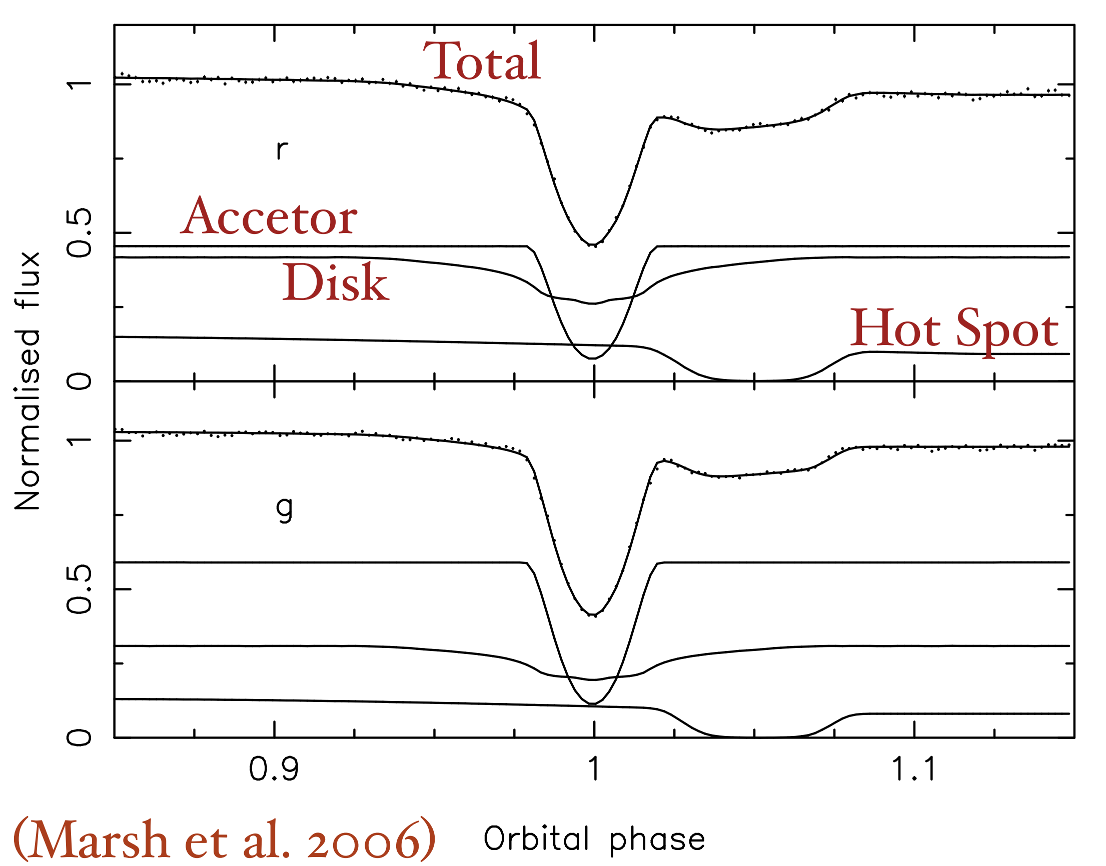

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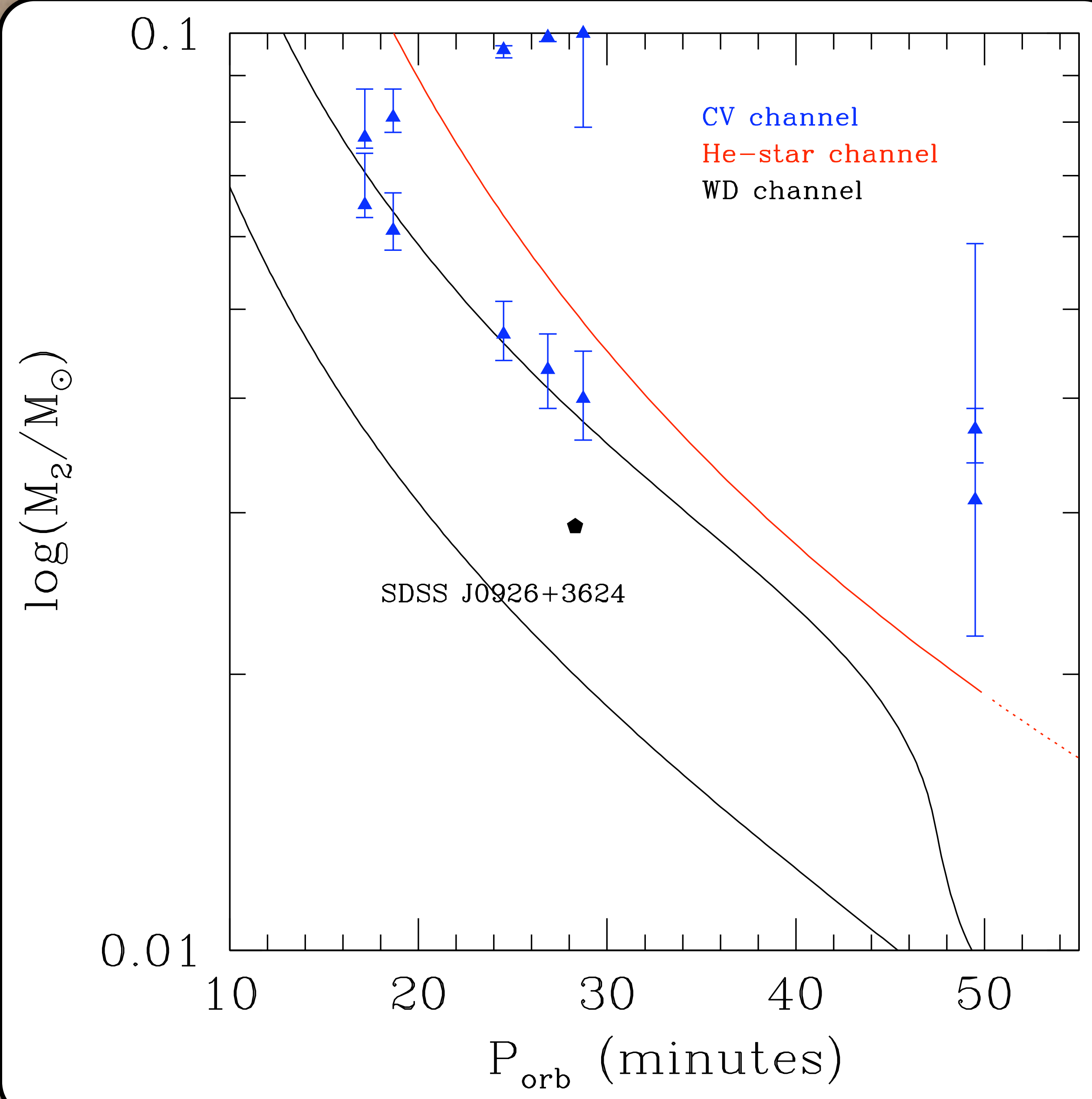

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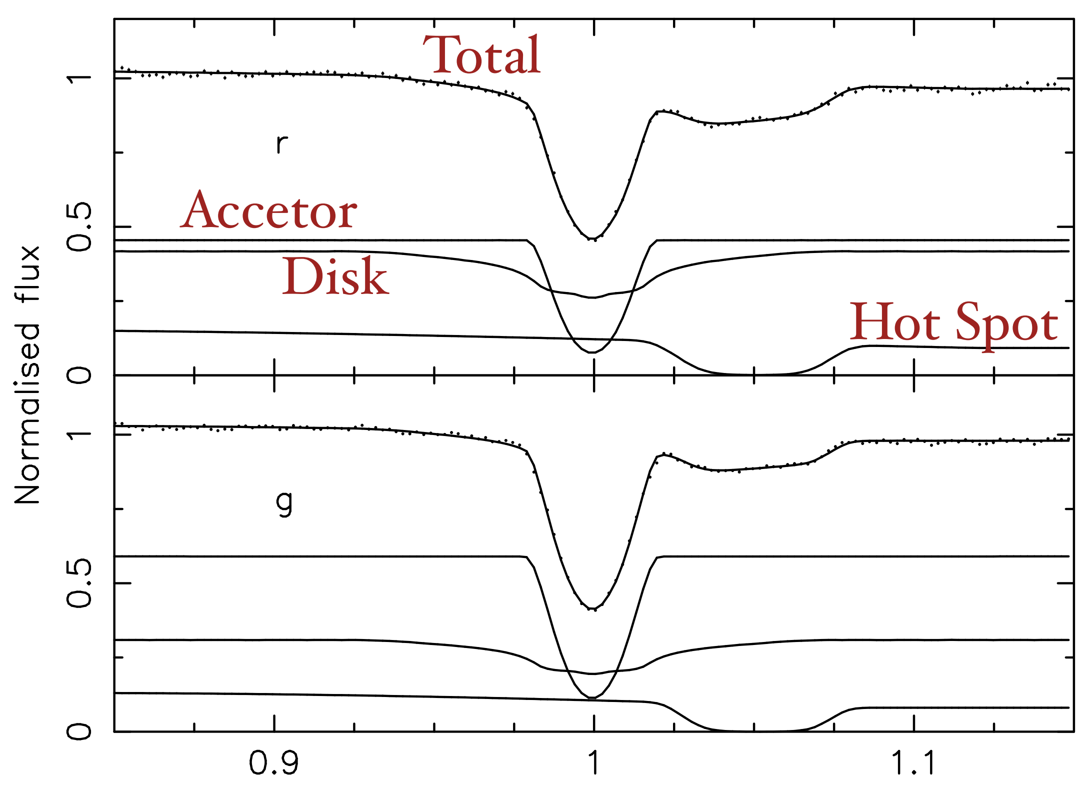

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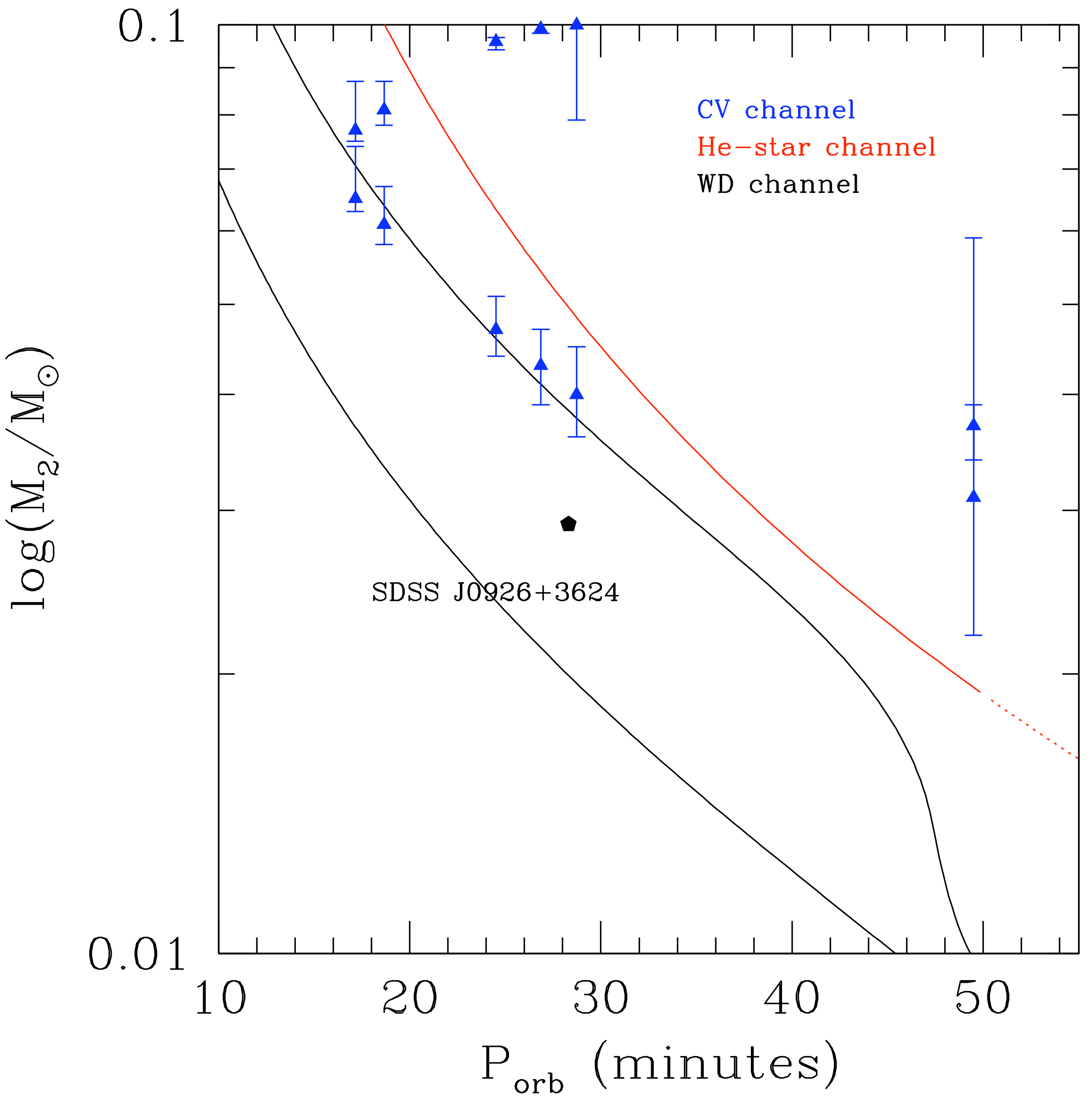

- Provides firm evidence that:

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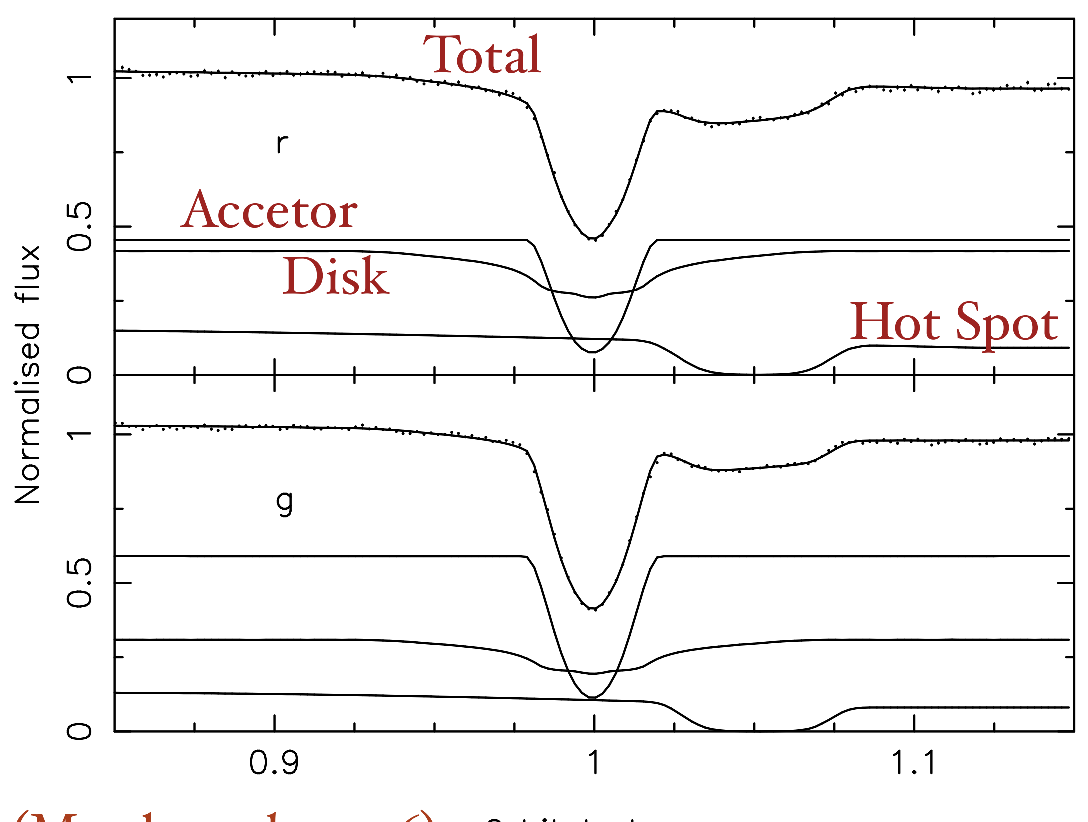

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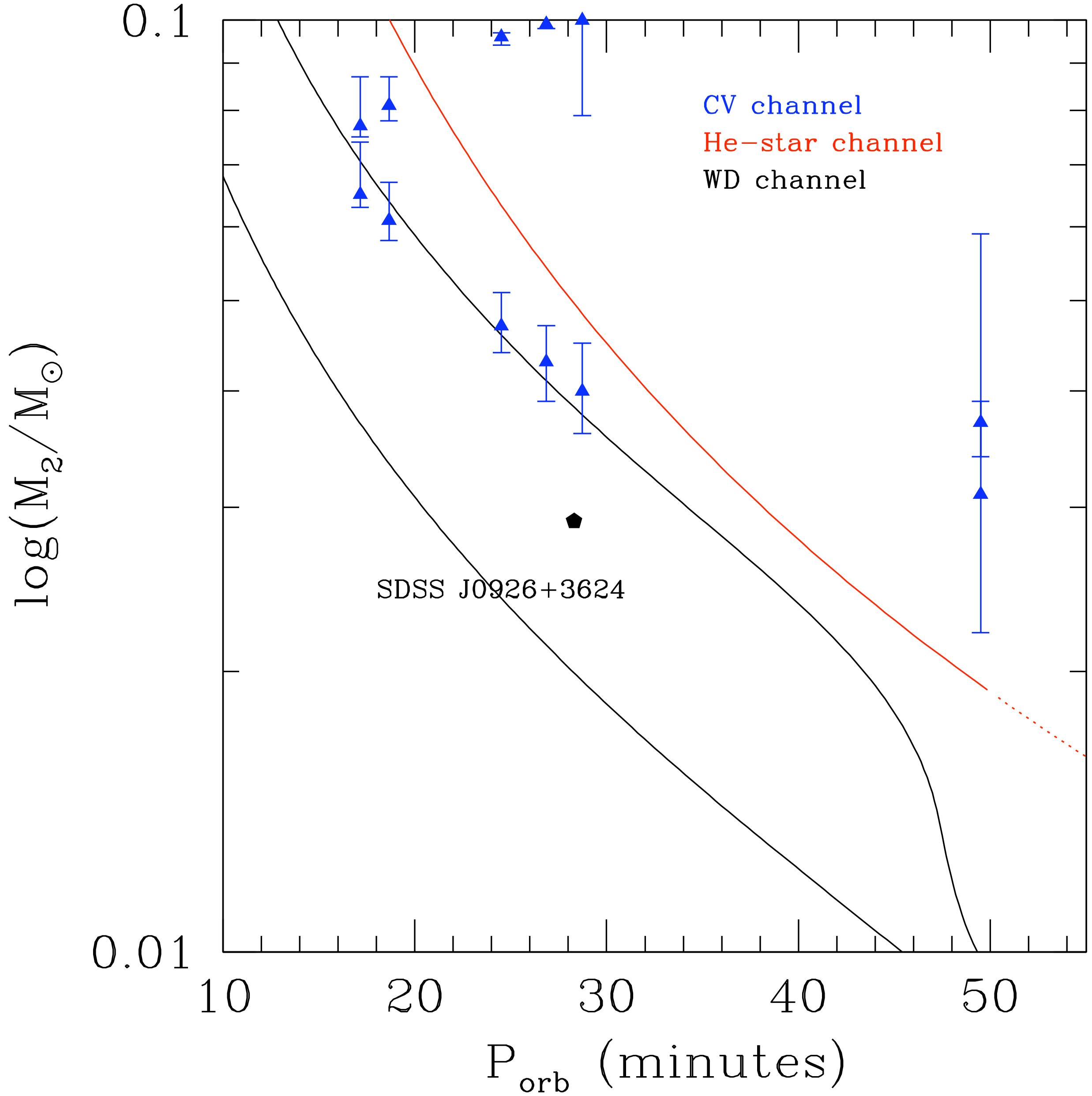

- Provides firm evidence that:
  - *WD channel contributes to AM CVn population.*

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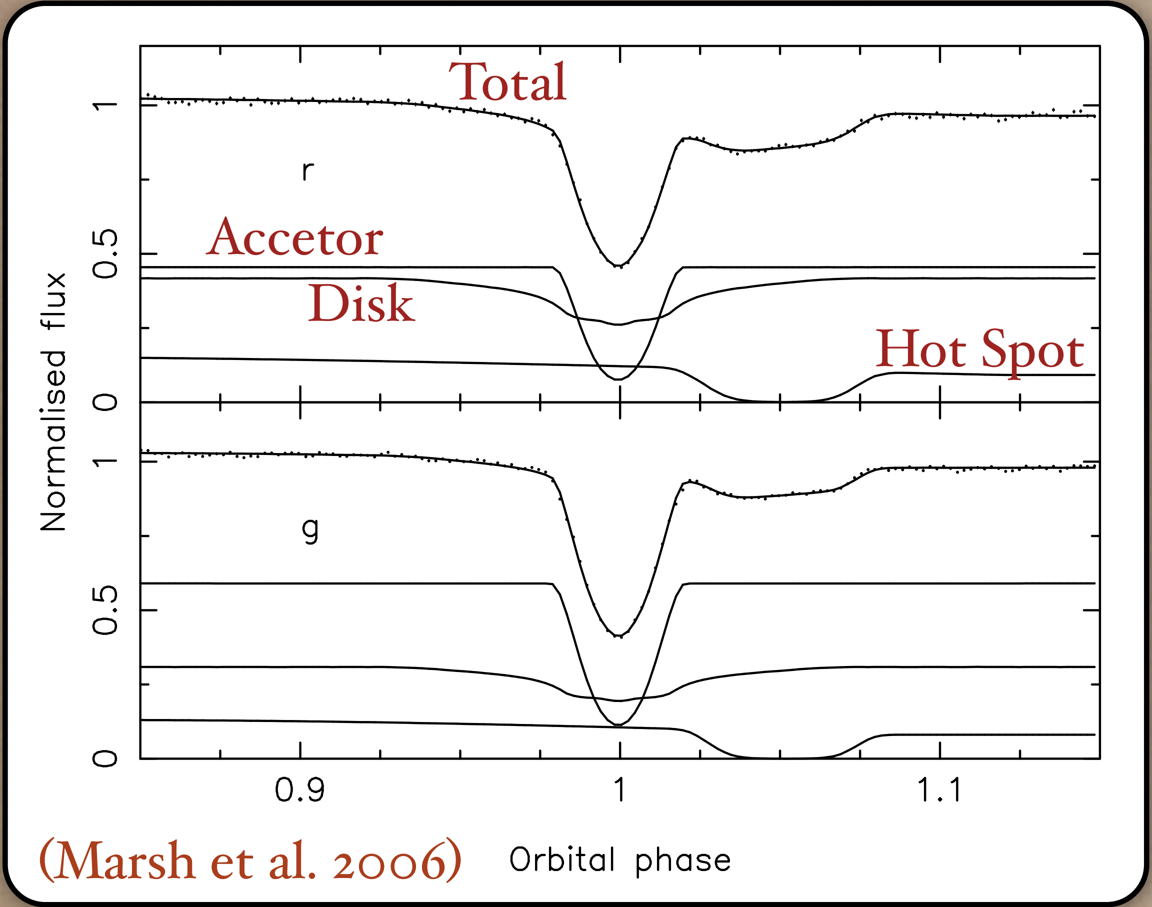

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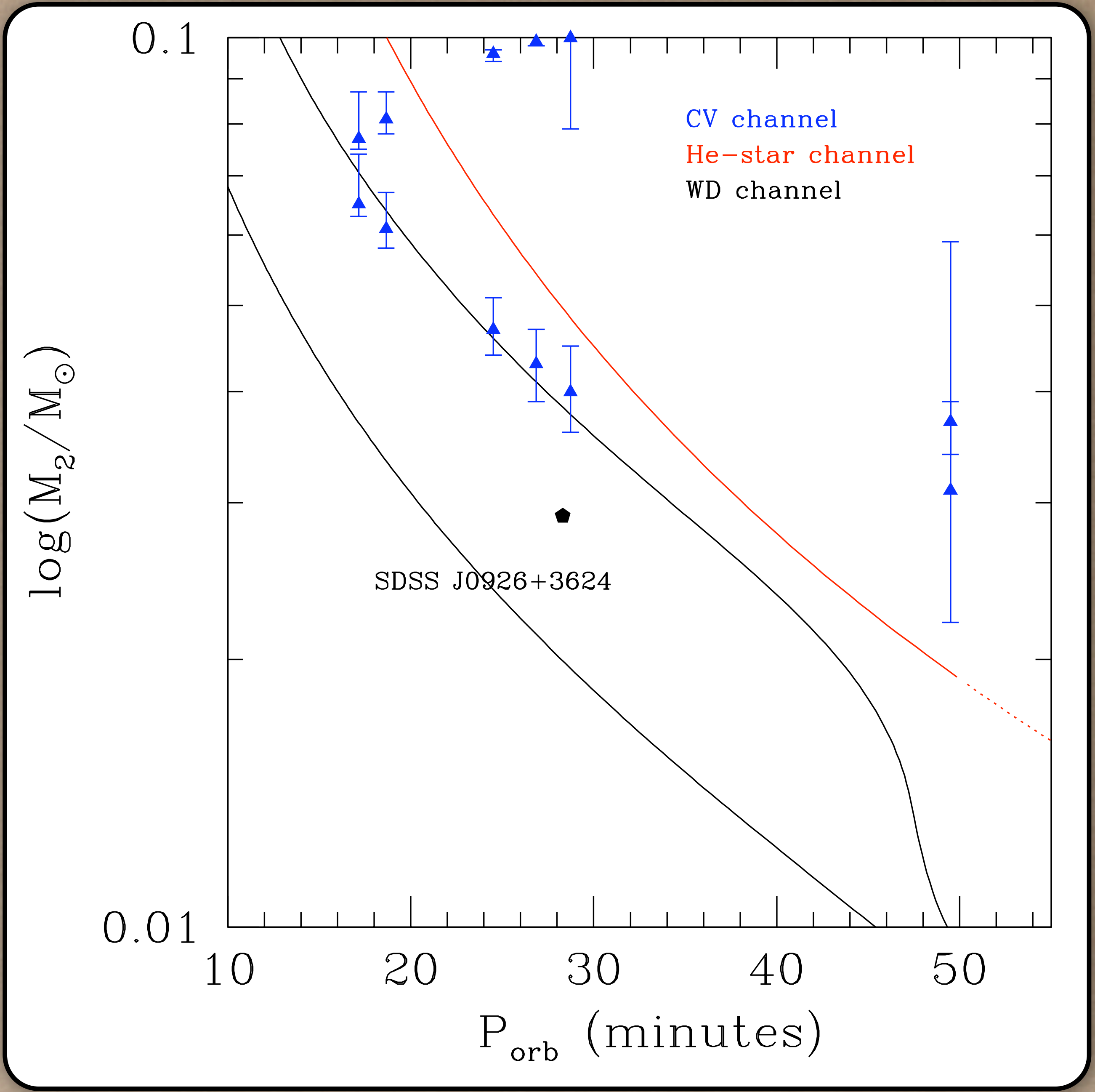

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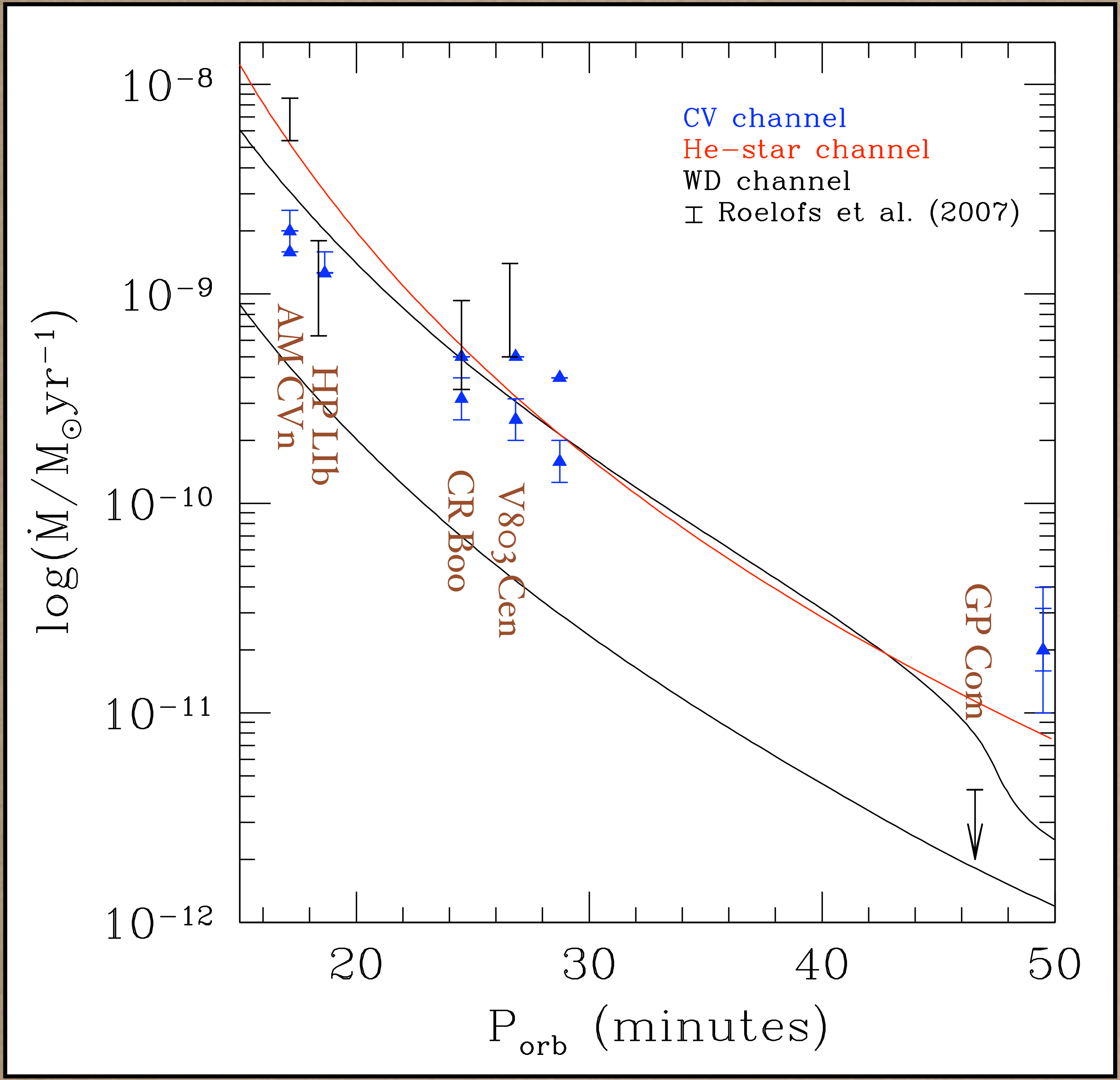
  - *Donors with non-zero entropy are produced in WD channel.*

Observational Data II: Secular Mass Transfer Rate Estimates



- 5 systems with recent *HST* parallax determinations (Roelofs et al. 2007).
- Mass-transfer rate estimates depend on:
  - M_V, BC.
  - $q=M_2/M_1$ (determined from kinematics or superhump period).
  - disk inclination (from kinematics or disk modeling), except for GP Com.
- Results:
  - Short-period systems appear inconsistent with having $T=0$ donors.
  - Some systems appear inconsistent with WD channel origin.
  - GP Com flux probably dominated by cooling accretor, so $\dot{M}$ constraint is only an upper limit.

Observational Data III: Composition and Number Density of AM CVns

- Abundance Patterns:
  - No convincing indication of H in any AM CVn spectrum. E. g.,
    - Disk spectra modeling of AM CVn, HP Lib, CR Boo, and V803 Cen (Nasser et al. 2003).
    - No H features in observed optical spectra of ‘SN 2003 aw, SDSS J1240-01, or GP Com (Roelofs et al. 2005, 2006, Morales-Rueda et al. 2003).
  - CNO abundances: either N features the only seen or N is dominant CNO element:
    - Only N features seen SDSS J1240-01 and GP Com (Roelofs et al. 2006, Morales-Rueda et al. 2003).
    - XMM Newton observations of CR Boo, HP Lib, AM CVn, GP Com, Ce-315, and SDSS J1240-01 all show N elevated to levels expected for CNO-processed ashes (or even higher) (Ramsey et al. 2005, 2006);
- Space density of AM CVn systems:
  - Observational estimates consistently of order 10^{-6}-10^{-5} pc^{-3} (Warner 1995, de Groot 2001, Roelofs et al. 2007a, 2007b).
  - Most pessimistic theoretical model predicts 10^{-4} pc^{-3} (Nelemans et al. 2001).

Putting it All Together

- CV Channel:
  - Lack of H in any system is a big strike against this being a significant contributor to AM CVn population.
  - Can we provide a firm explanation for why this channel appears not to contribute?
- He-star channel:
  - Possibly required by high mass transfer rates in several systems.
  - If this channel does contribute, is there a reasonable explanation for no He-burning products in any system?
  - Donor's progenitor lacks sharp core/envelope entropy contrast leading to merger in second CE-event (e.g., Taam & Ricker 2006).
- WD channel:
  - SDSS J0926+3624 provides definitive evidence that this channel contributes to AM CVn population.
  - No evidence for the cold donors that should dominate this channel's contribution (Deloye et al. 2005).
  - All system's abundances appear consistent with that expected from all systems in this channel (He-dominated, N-rich, and H-free).

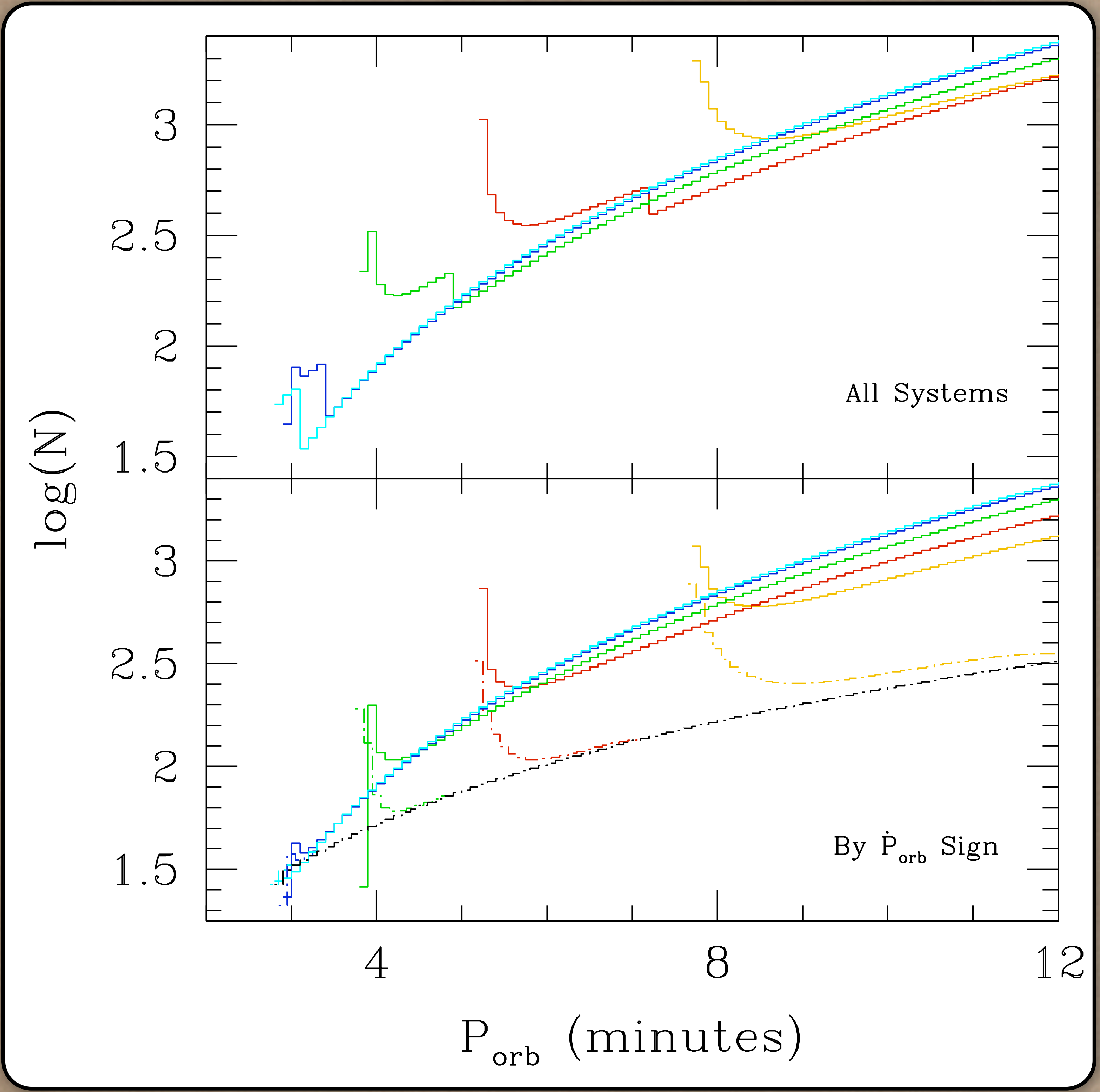
Possible Synthesis (i.e, Almost Rampant Speculations)

- He-star channel systems all merge in CE.
- WD channel systems are the only contributors to AM CVn population:
  - Observed abundances naturally explained.
  - Maximum entropy in this channel set by donor's pre-contact cooling rate, which current modeling is likely overestimating.

    ⇒Could provide explanation for highest mass-transfer rate systems.

  - Only need 10% of WD channel systems to survive contact to explain observationally inferred number density of AM CVn population:
    - Direct impact accretion leads to unstable mass-transfer at contact in this channel (Marsh et al. 2004).
    - Hotter donors and more massive accretors tend to stabilize mass-transfer, so such systems preferentially survive to become AM CVns (but see also Gokhale et al. 2006).
    - Prediction: observed systems should all have far from zero-entropy donors and higher than expected total system mass.
    - Details need to be worked out to see if this is viable explanation.

Finally, a look Ahead: Diagnostics in the *LISA* Era



- WD channel systems near P_{orb}-minimum (Deloye et al. 2007):
  - Donor entropy sets minimum-P_{orb},
  - Model evolution from contact to this minimum and back out, producing slowed P_{orb} near the P_{orb}-minimum.
  - P_{orb}-evolution rate determines intrinsic contribution each systems makes to population's number density.
  - Diagnostic of system parameters leading to mergers vs. surviving as binaries.
- In the meanwhile: develop additional observational tests, particularly concerning relative expectations for non-AM CVn outcomes.
  - E.g., how many He-nova and/or SNe Ia events are expected from WD channel systems given various assumptions for prior binary evolution?