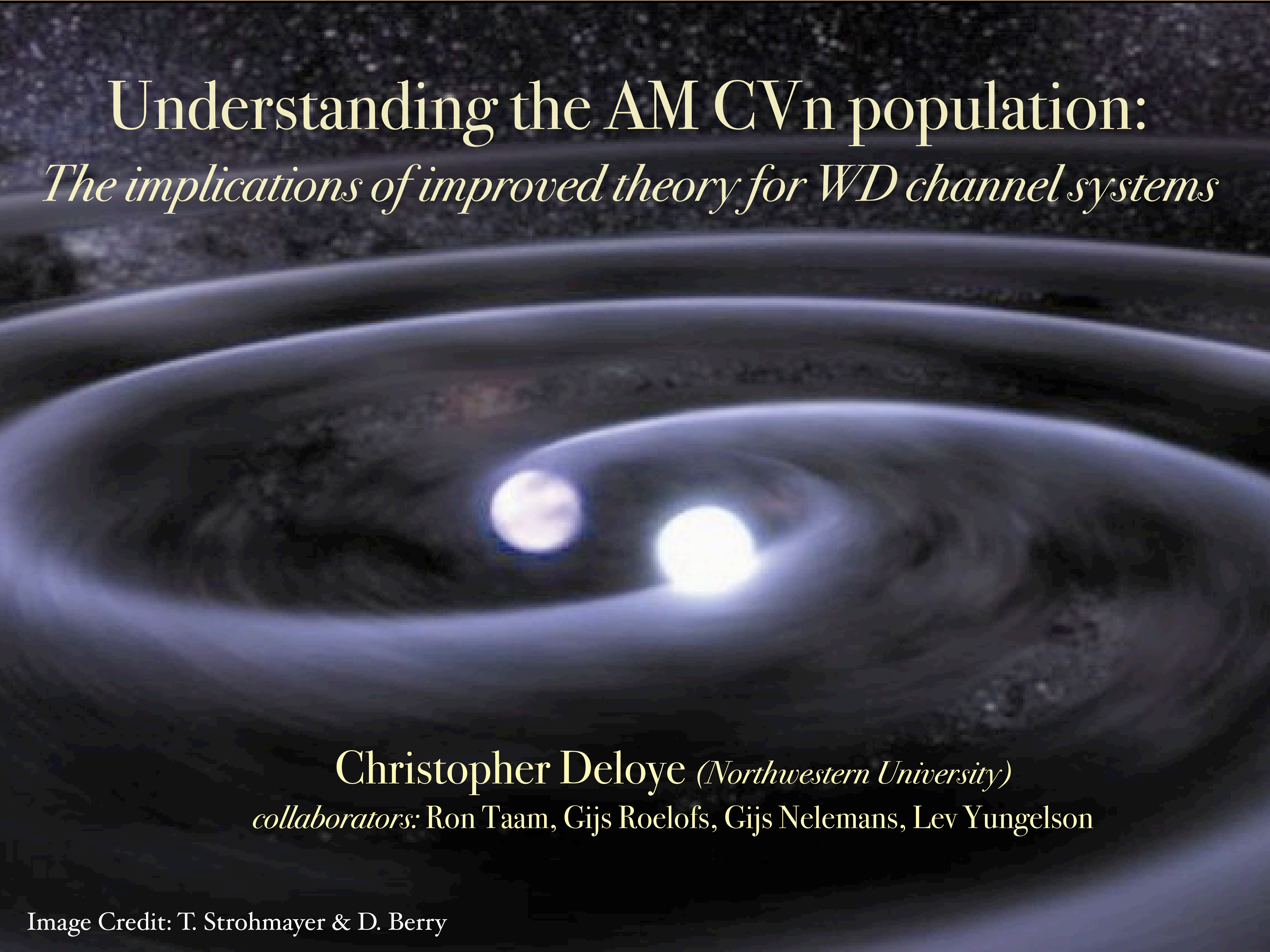
Understanding the AM CVn population:

The implications of improved theory for WD channel systems



Christopher Deloye *(Northwestern University)*

collaborators: Ron Taam, Gijs Roelofs, Gijs Nelemans, Lev Yungelson

Image Credit: T. Strohmayer & D. Berry

Outline

- AM CVn formation: Three Channels.
- Focus on WD channel
    - Donors: arbitrarily degenerate He WDs.
    - Insights and expectations from recent theory advances.
    - *Stark* disagreement with recent observational data.
    - Implications for WD Channel system's formation and evolution.
- Looking forward
    - Further observational tests.
    - The broader context.

To Clear up Confusion

AM CVn noun, proper (*slang, or at best, archaic jargon*)
1. A variable star located in the constellation Canus Venaticorum peculiar in its marked absence of hydrogen, very short period of variability, and very blue color.

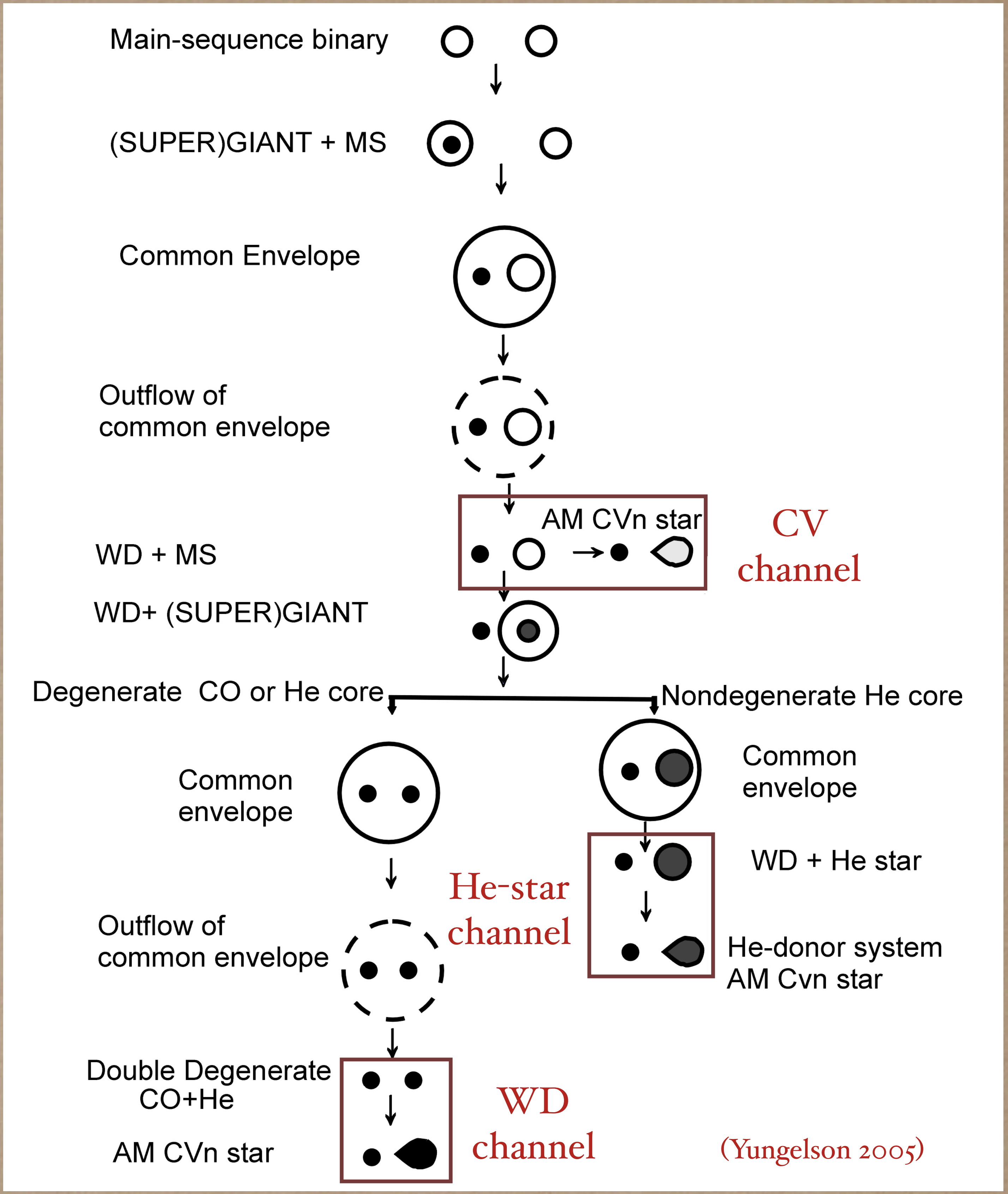
AM CVn binary (or star, variable) noun (*even worse archaic jargon*)
1. Any member of a class of variable stars sharing properties similar to AM CVn.
2. An interacting stellar binary whose:
   i. accretor is a white dwarf
   ii. global minimum orbital period can be measured or inferred to be less than that of classical cataclysmic variables (roughly 70 minutes) during its most recent episode of continuous mass transfer.

   The second condition implies that the donor has processed at least a significant fraction, if not all, of its core H into He (and possibly further into C/O in some hypothetical cases) before the system's global orbital period minimum is reached.

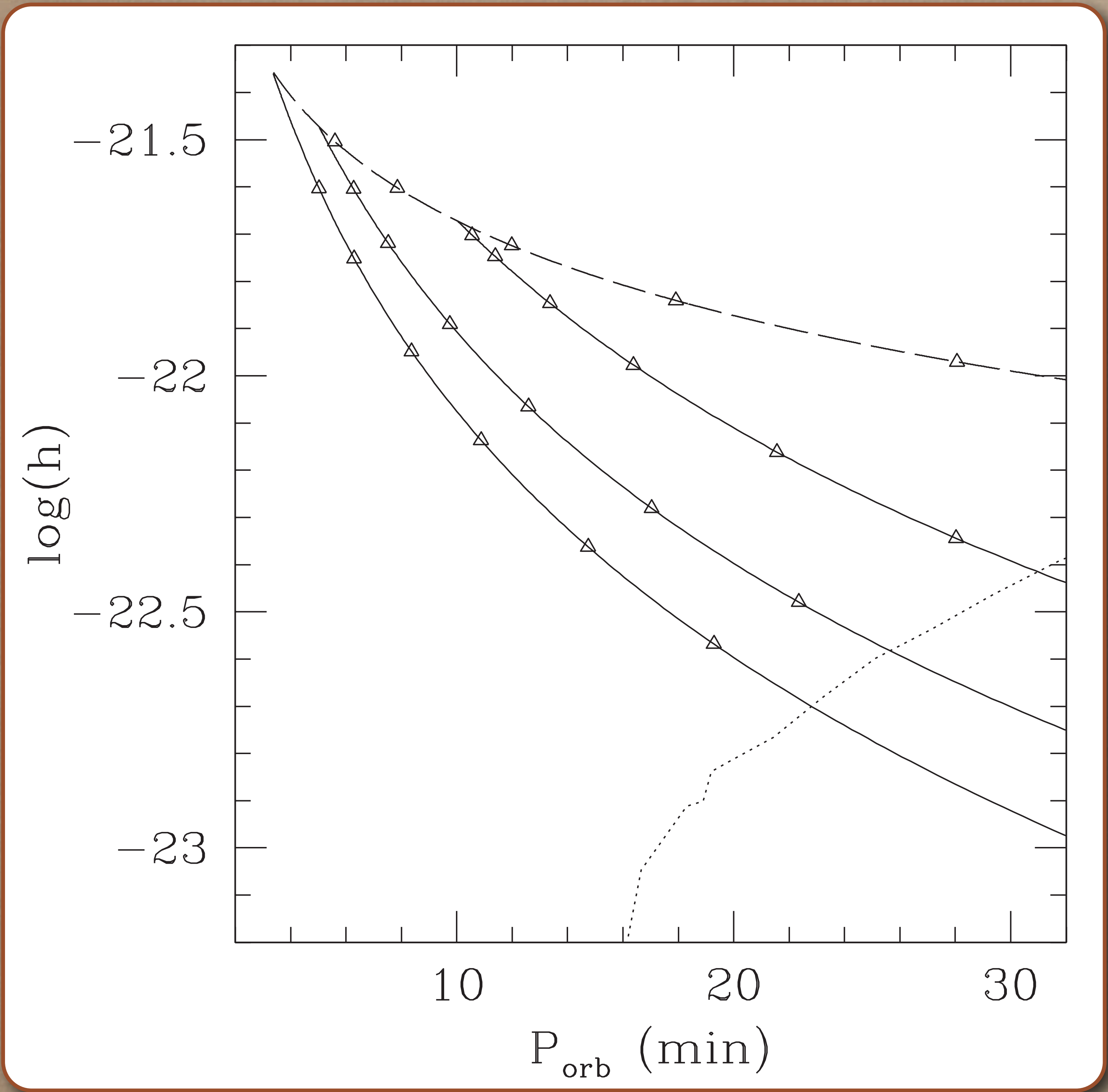
   Three distinct formation channels are commonly discussed for AM CVn binaries, one of which can be connected to the classical cataclysmic variable population via a continuous variation of a single-parameter.

AM CVn Formation Channels

- Possible formation channels:
  - CV channel: single CE → WD+Evolved-MS (Podsiadlowski et al. 2003)
  - WD channel: double CE → WD+WD (Nelemans et al. 2001)
  - He-star channel: double CE→WD+He-star (Nelemans et al. 2001)
  - Formation channels influence post-contact evolution.
- Donor properties vary within each channel:
  - CV channel: H content, minimum orbital period.
  - WD channel: donor entropy, contact orbital period.
  - He-star channel: core He vs. C/O fractions.
- *Will focus on WD channel.*



WD Channel AM CVns: Overview of Post-CE Evolution



- Binary evolution driven by gravity wave angular momentum losses.
- Evolution phases:
  - Detached in-spiral:
    - Donor cools and contracts.
    - Affects, in part, donor's entropy at contact.
  - Onset of mass transfer:
    - Donor entropy sets contact $P_{\rm orb}$.
    - Inward $P_{\rm orb}$ evolution continues for a time post-contact.
    - System survival???
  - Outward $P_{\rm orb}$ evolution under mass transfer.
    - "AM CVn" phase.
  - Prior modeling (Nelemans et al. 2001, Deloye et al. 2005) assumed
    - Isentropic donor structure.
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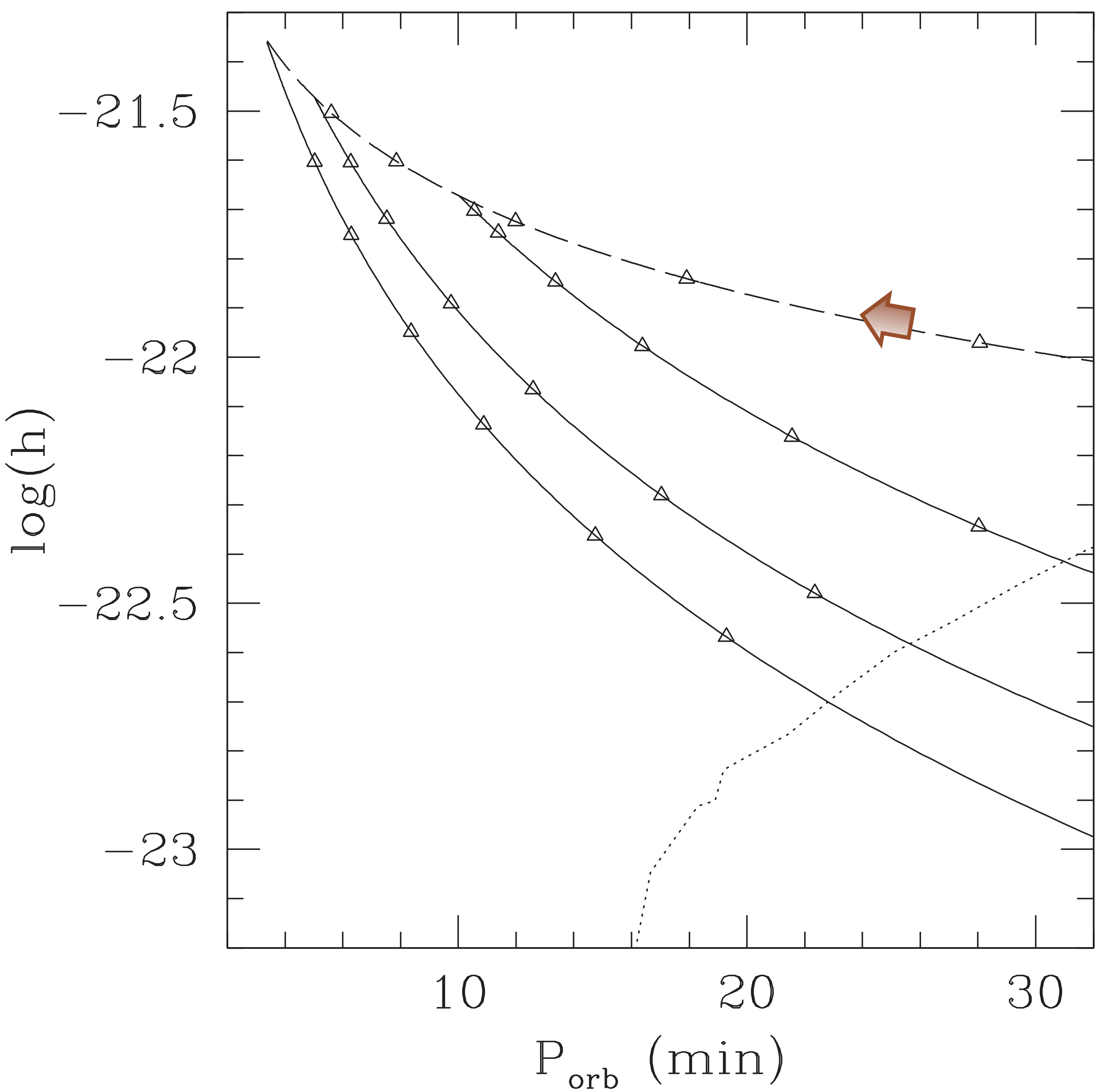

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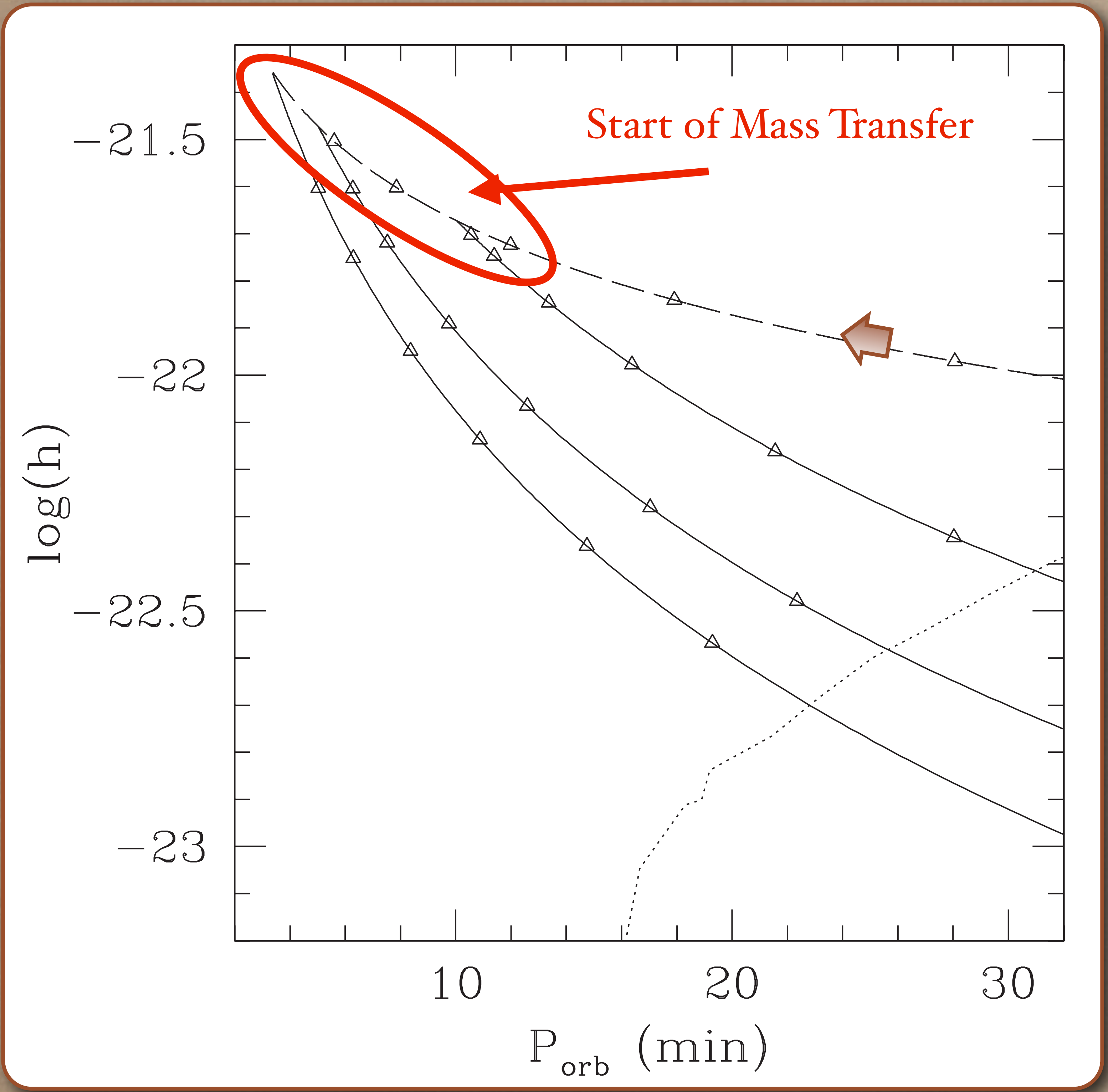

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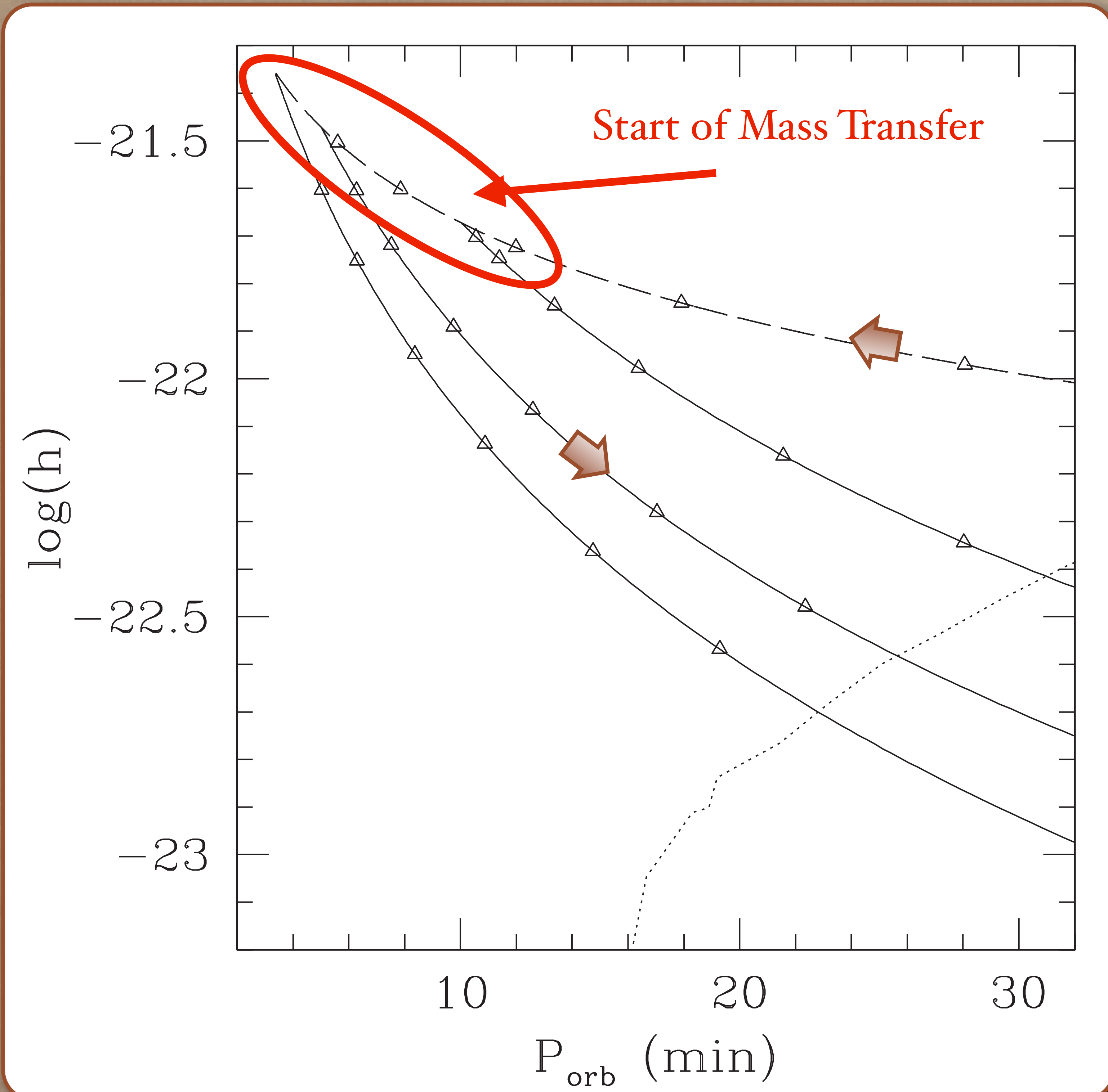

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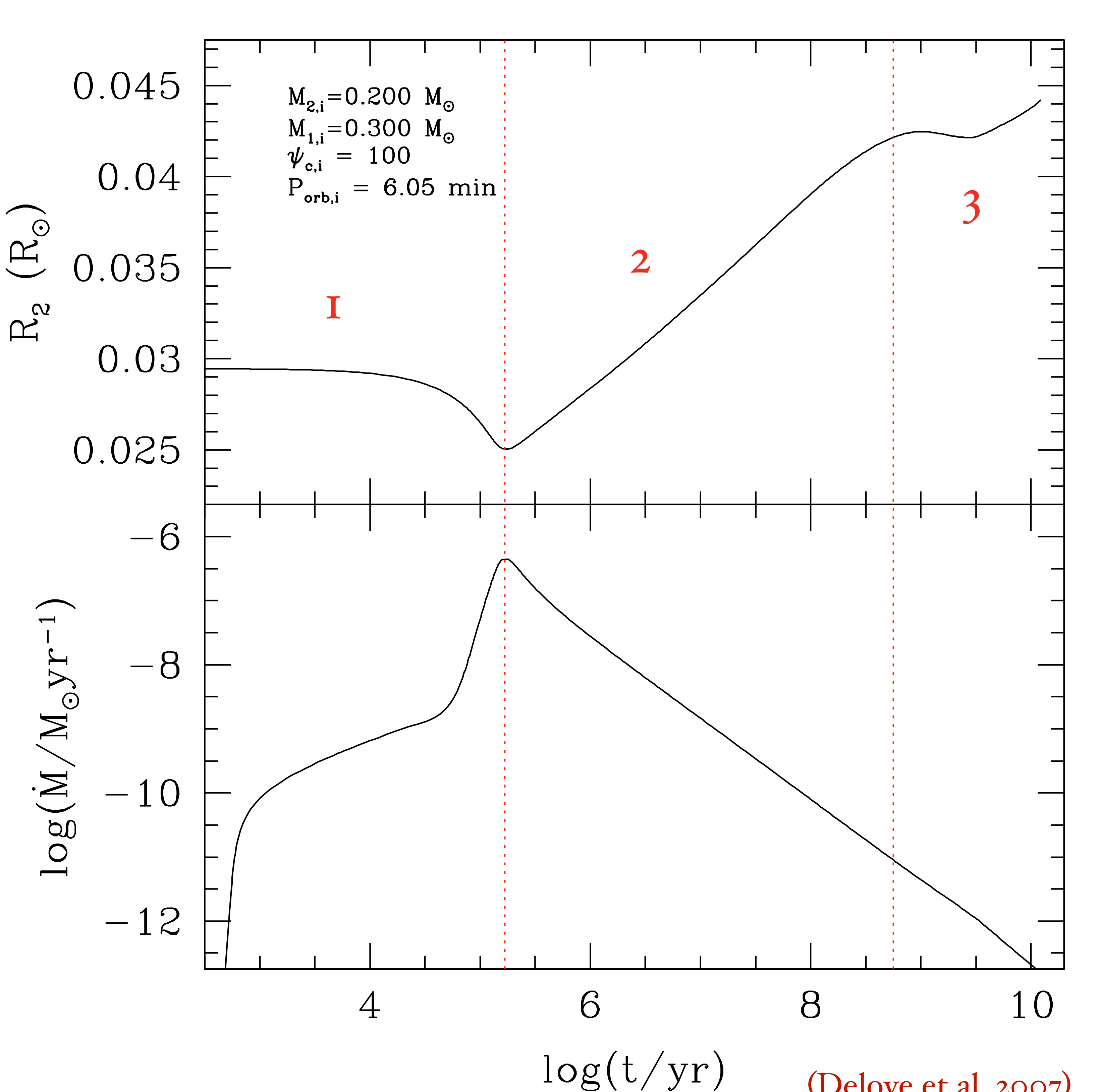
WD Channel Systems: Evolution with Realistic Donor Treatment



(Deloye et al. 2007)

- Present models: no assumptions about donor's:
  - structure.
  - thermal evolution.
- Evolutionary phases:
  1. Mass transfer turn-on: degeneracy-dependent donor contraction (non-isentropic outer layers).
  2. "Standard" AM CVn Phase (adiabatic donor expansion).
  3. Donor cooling (non-adiabatic thermal evolution).

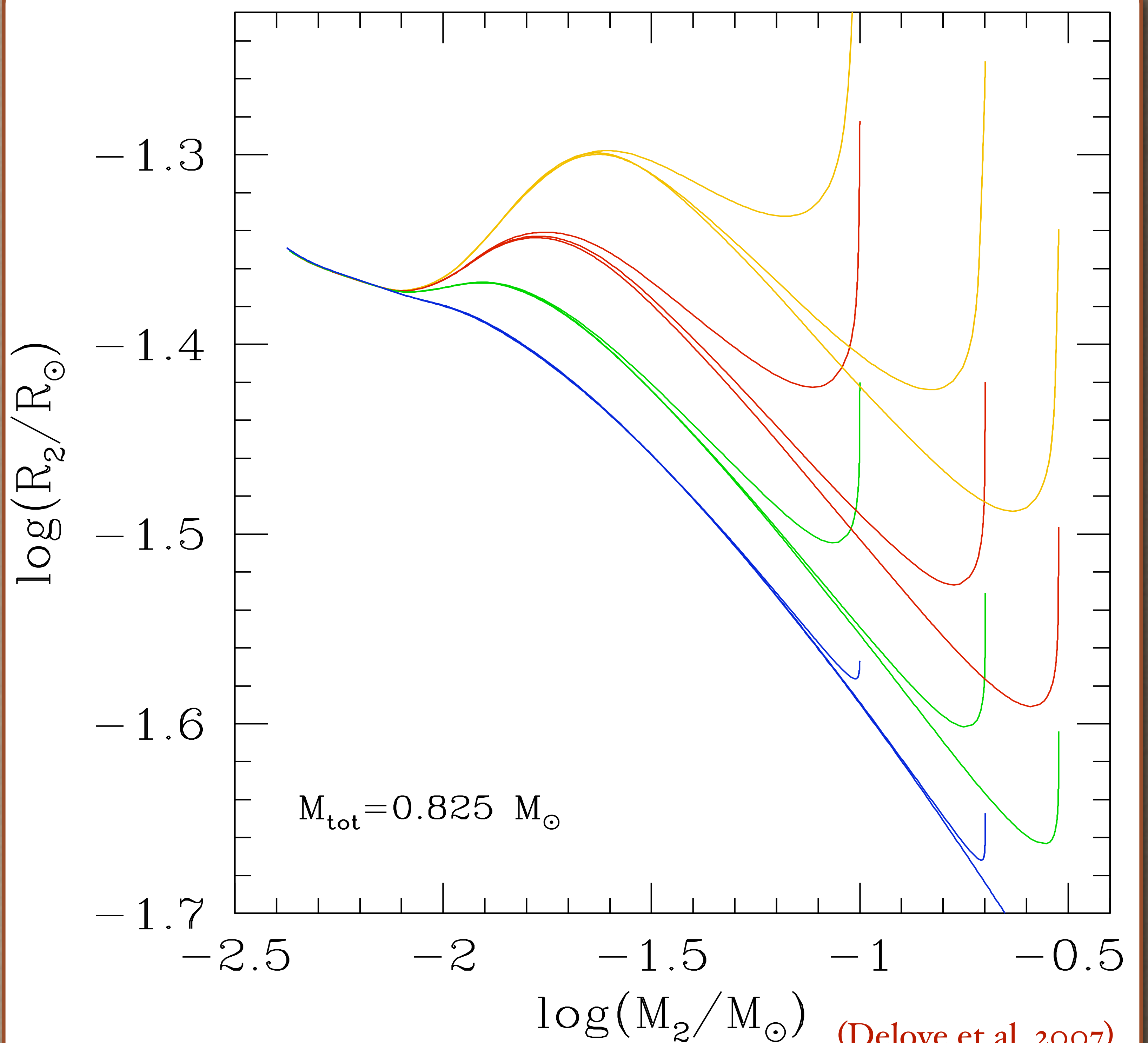
Relevant Time Scales:

$$\tau_{\rm th} \approx \frac{\int_0^{m'} c_P T dm''}{L} \qquad \tau_{\rm M} \approx \frac{m'}{\dot{M}}$$

$$(m' = M_2 - m)$$

Donor's Contact Entropy and AM CVn Phase Evolution

- Donor's initial entropy sets binary evolution properties during AM CVn phase.
- Observables influenced/ determined by donor's initial entropy:
  - M_2 vs P_{orb}.
  - $\dot{M}$ vs P_{orb}.
  - P_{orb} distribution (via distribution of initial donor entropy within population).



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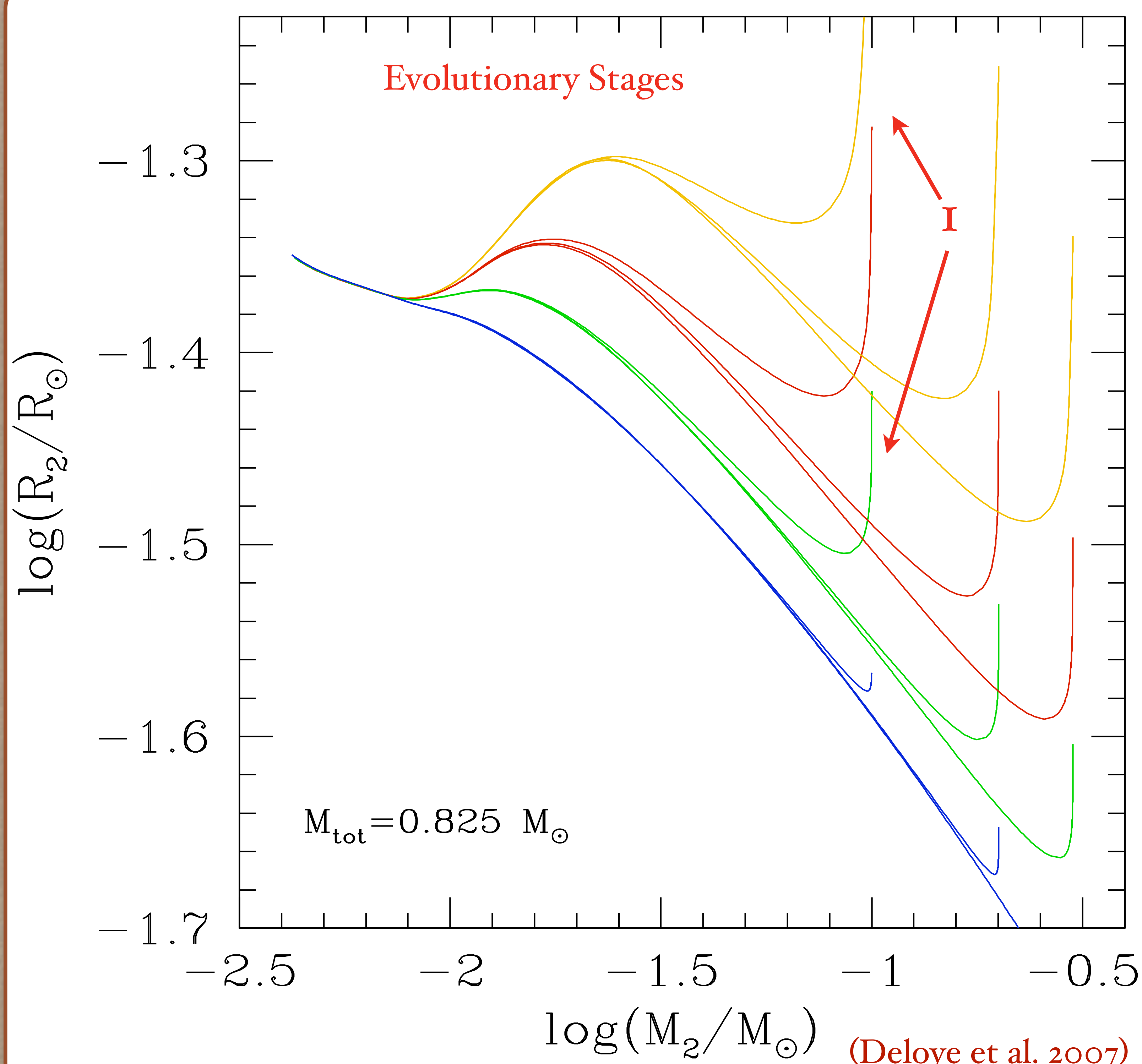

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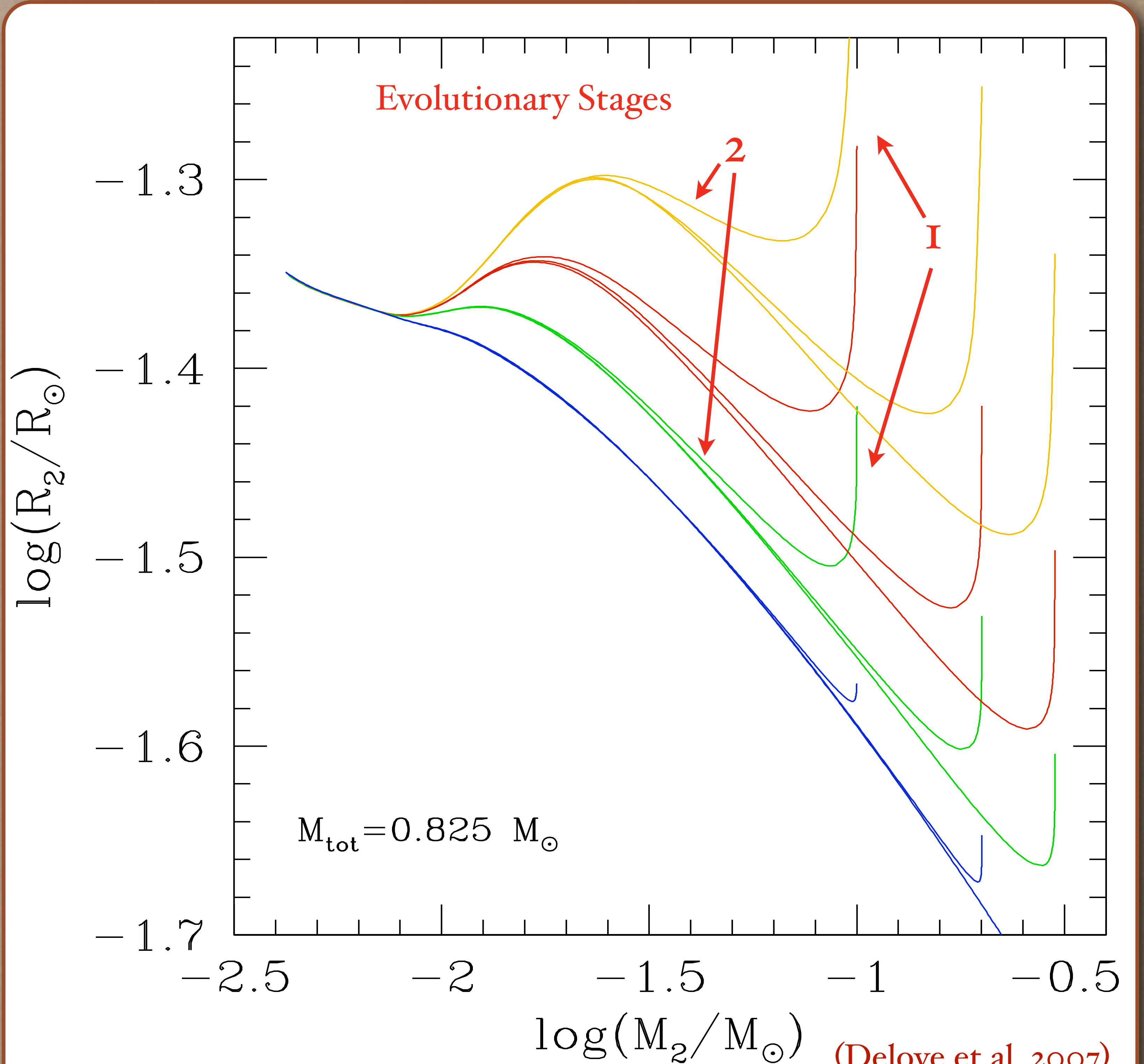

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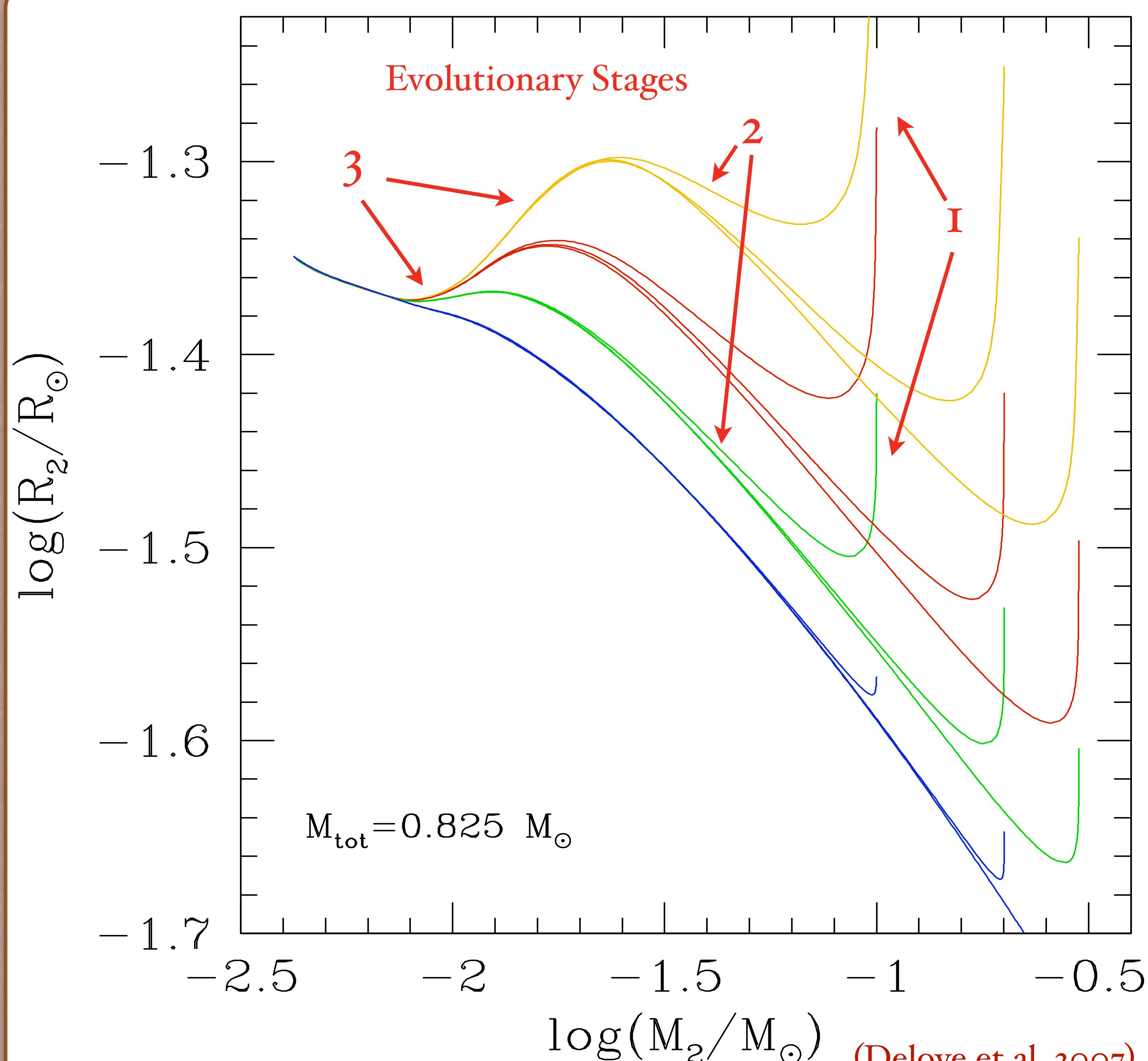

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The Entropy Distribution of WD Channel Donors

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  - Potential heating mechanisms (e.g., tidal heating).
- Theoretical entropy distribution:
  - influenced by population synthesis modeling inputs.
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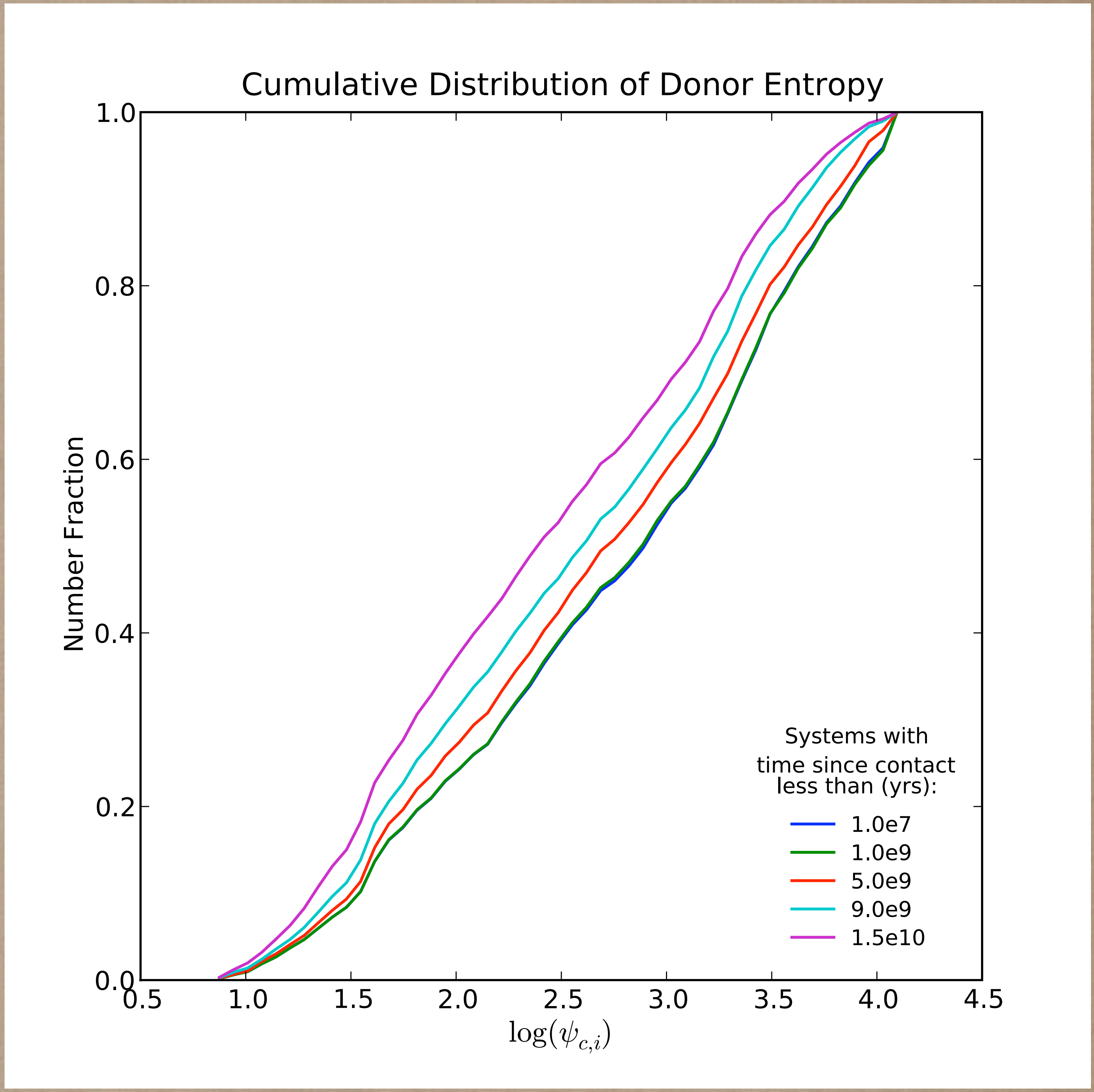
- Population distribution:
  - Entropy distribution *roughly* flat, but
  - R_2-distribution strongly peaked towards zero-temperature M_2-R_2 relation.



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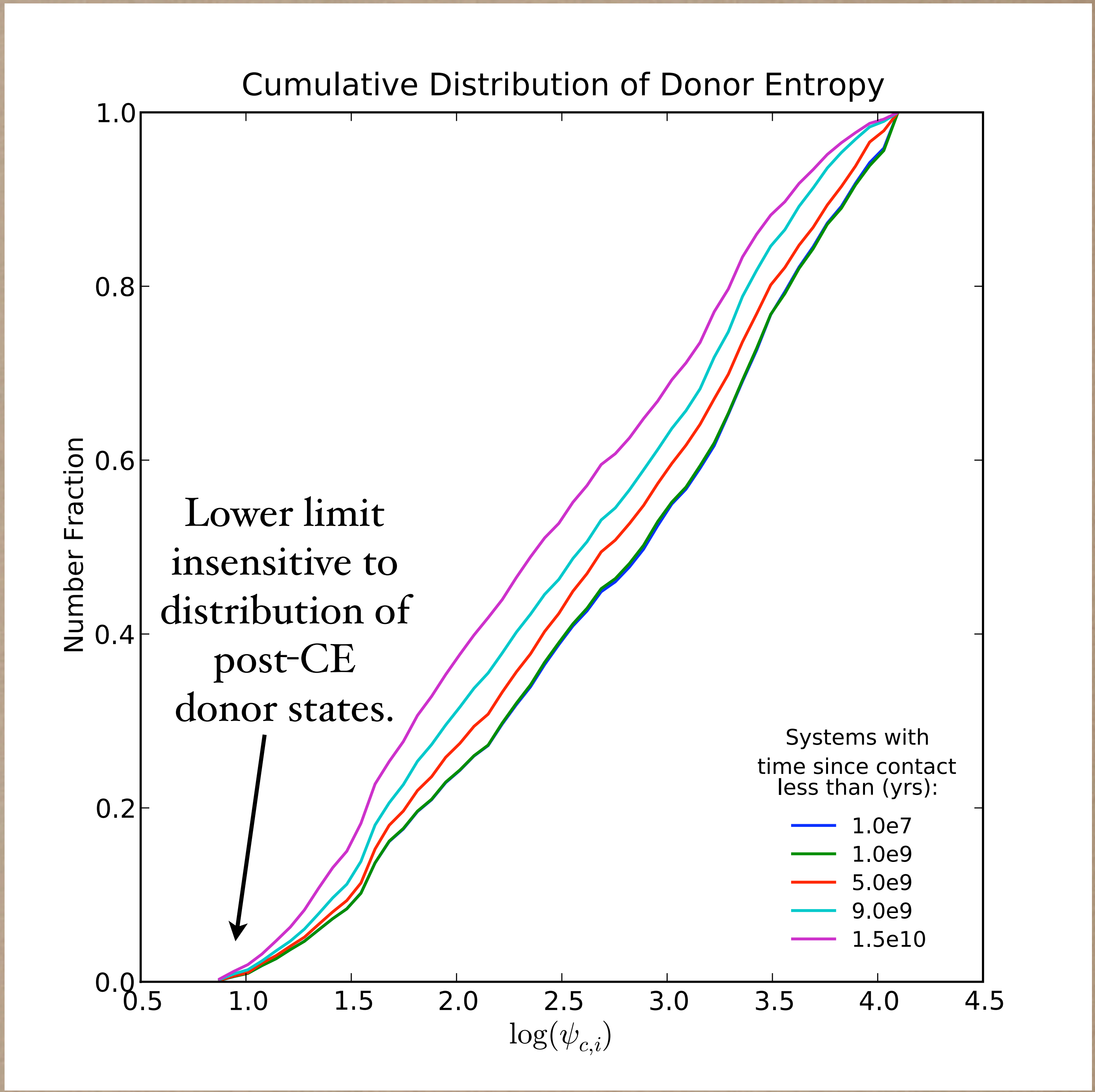

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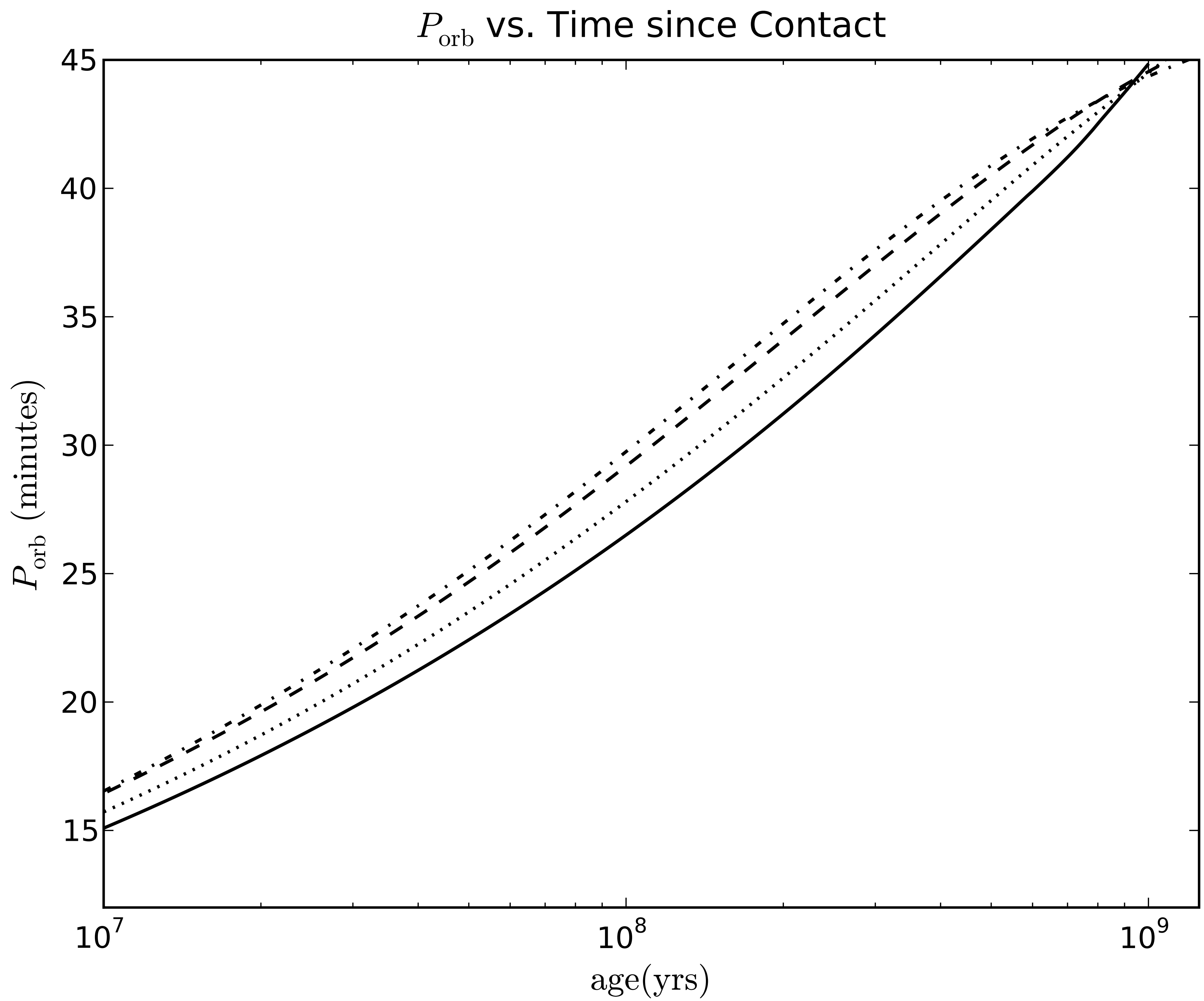

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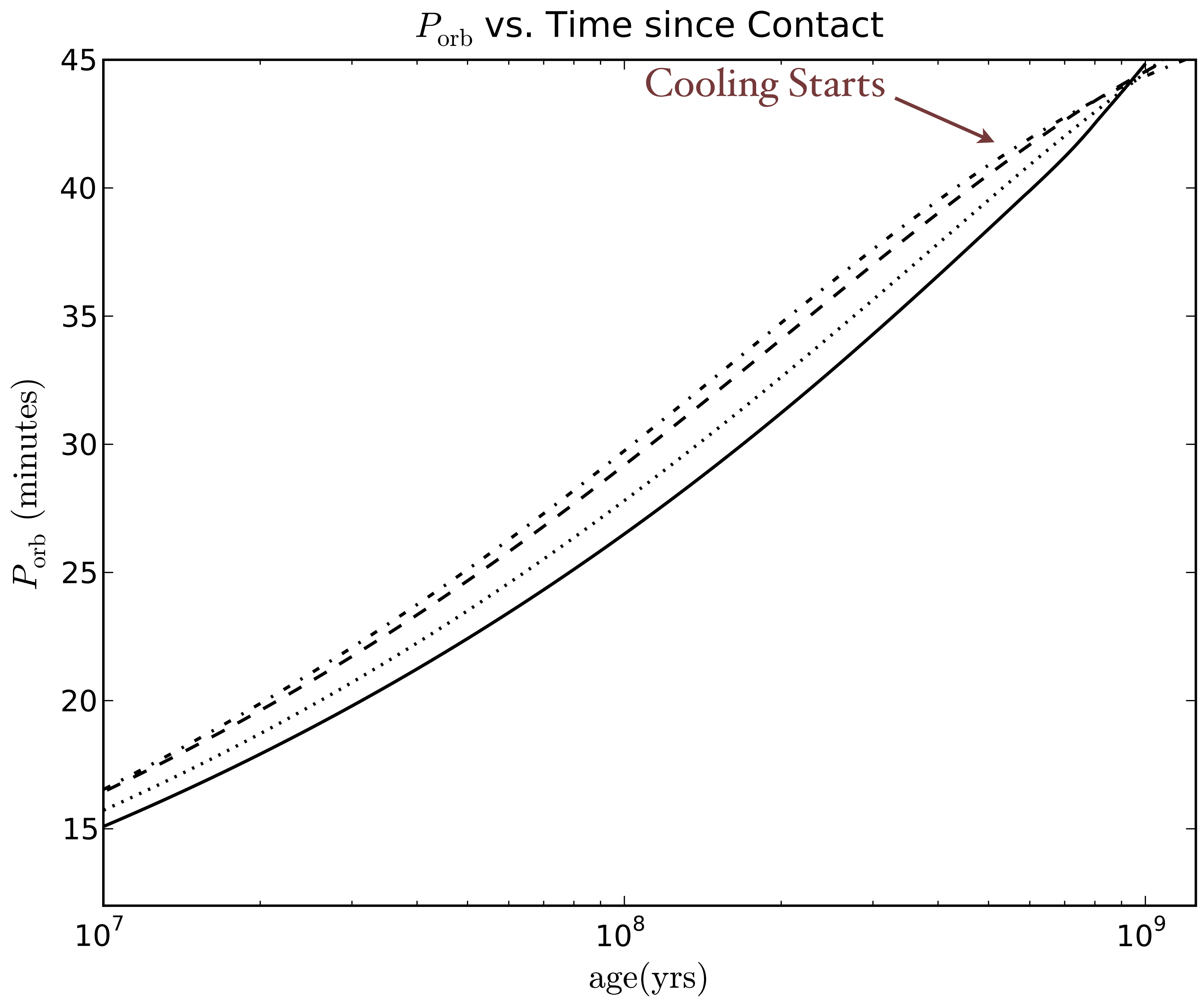

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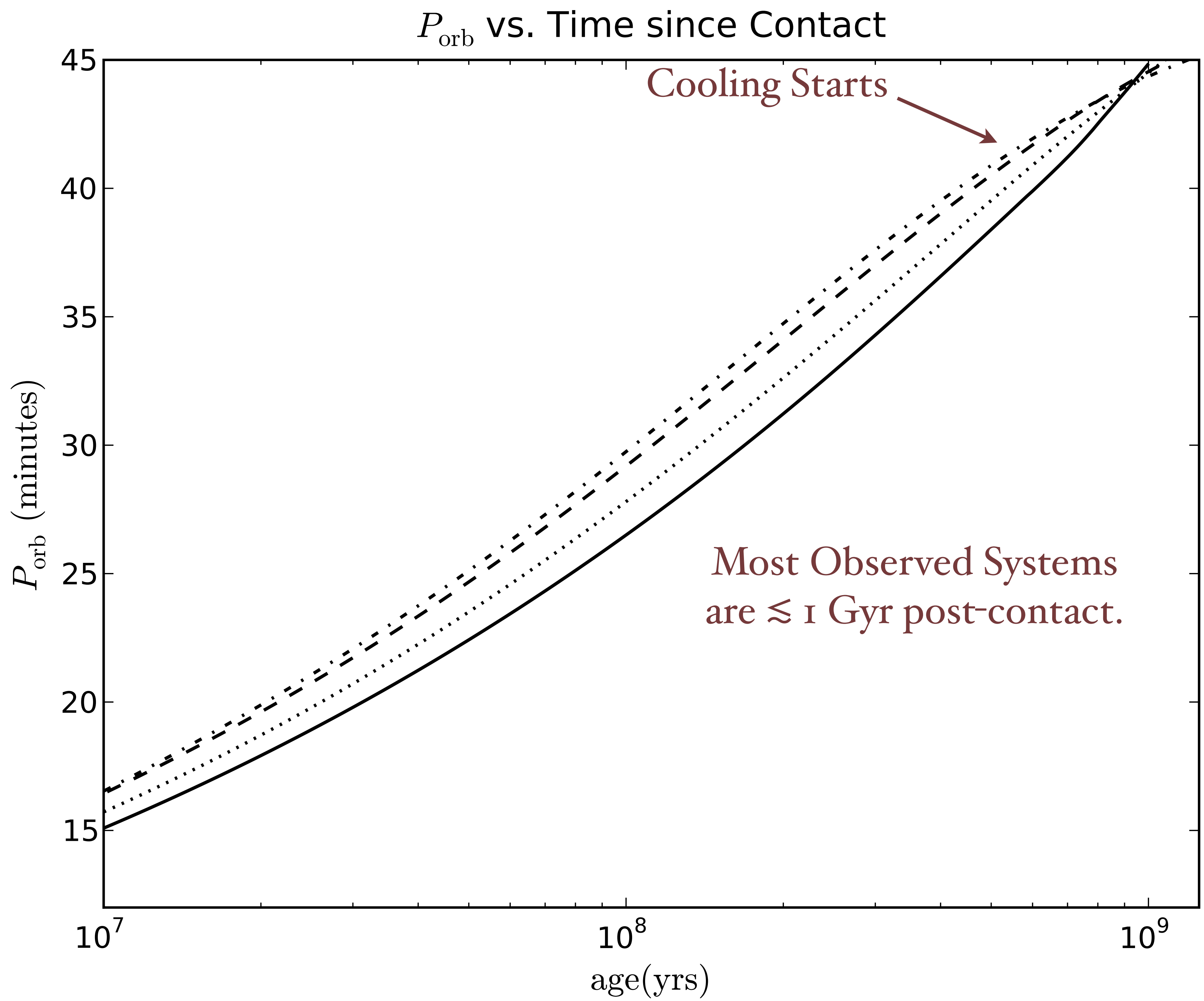
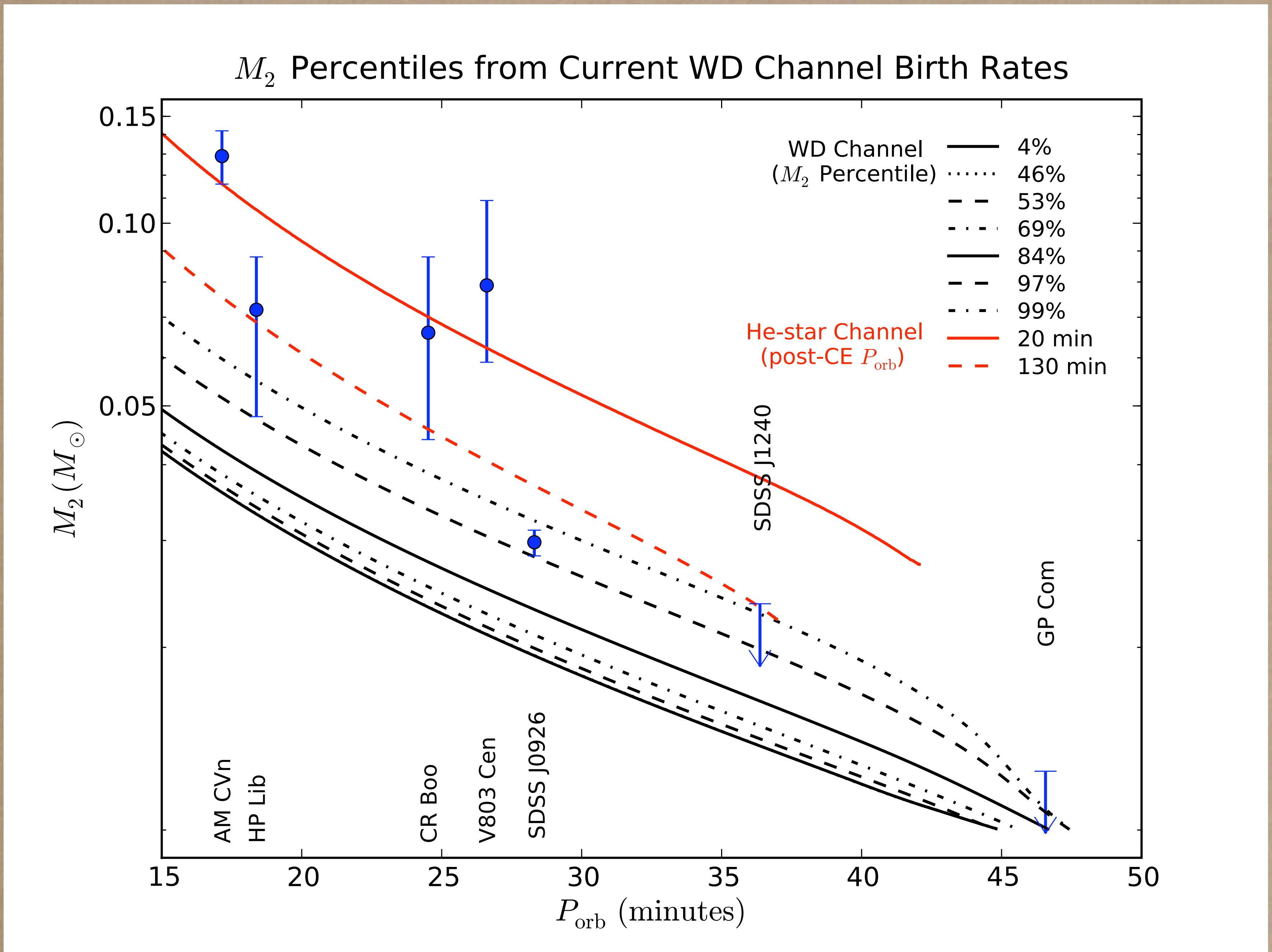


Distribution of Current System Properties: Theory vs. Observations



(He-star models: Yungelson 2008) (Marsh et al. 2006, Roelofs et al. 2007)

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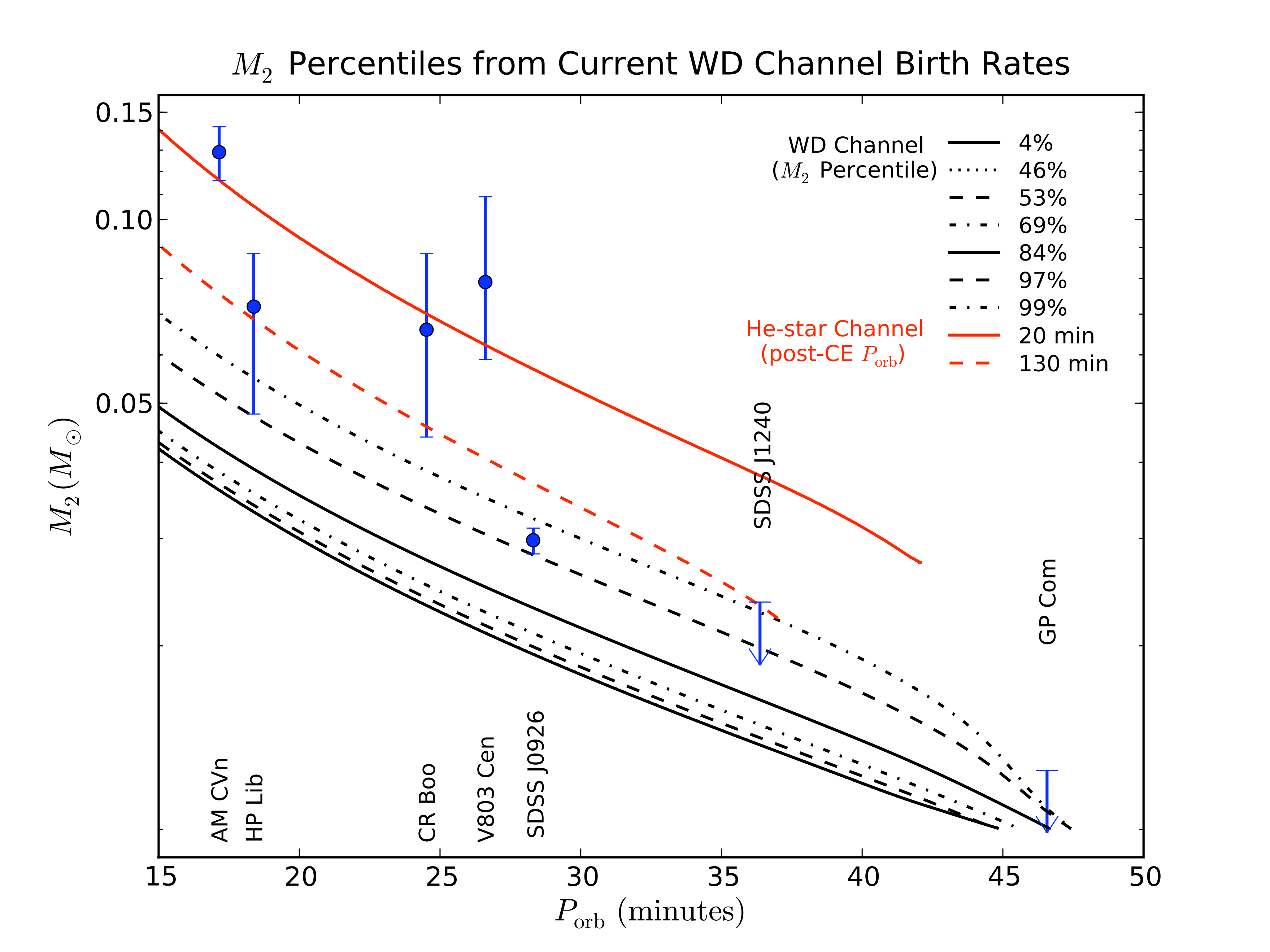

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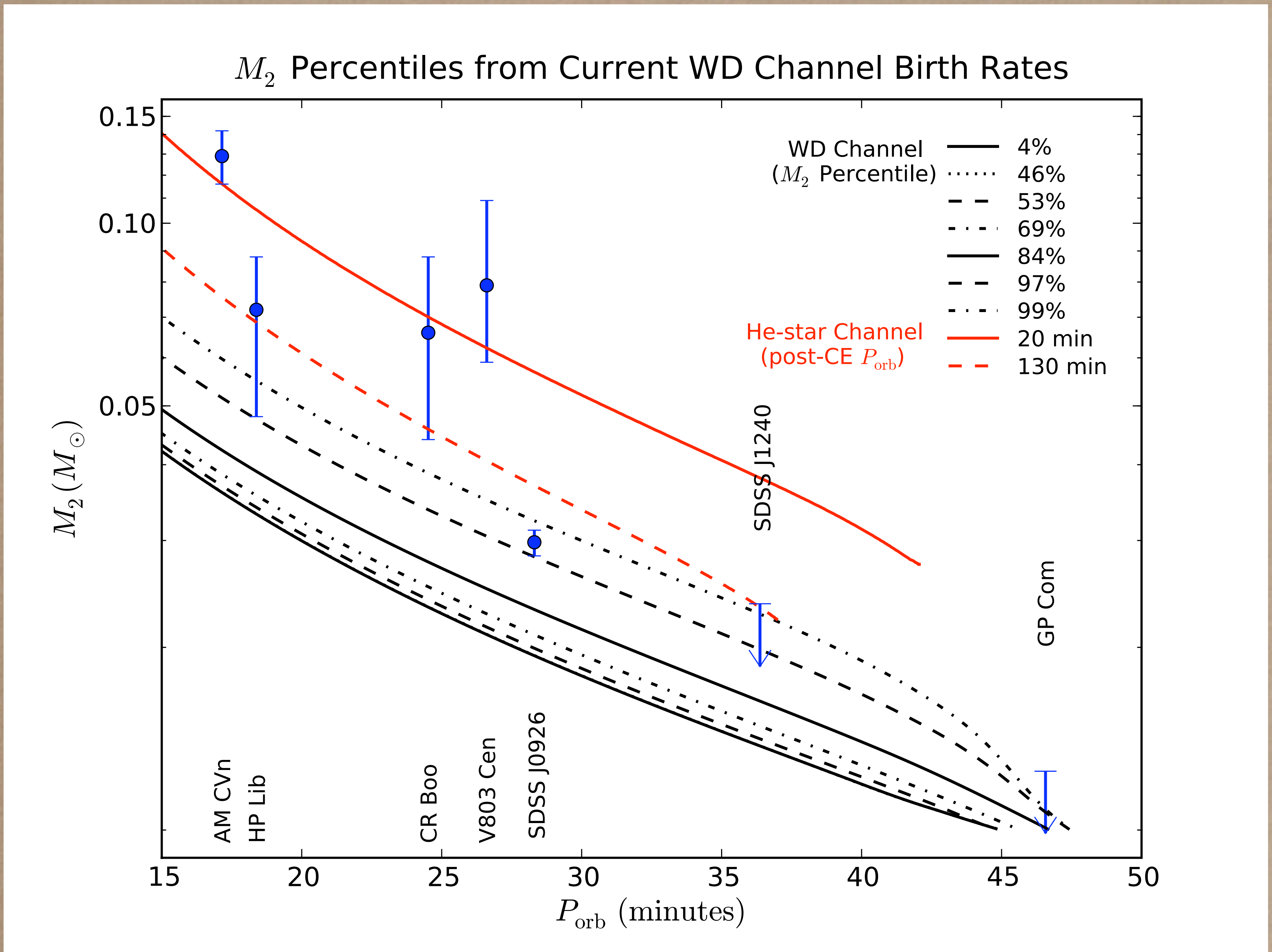

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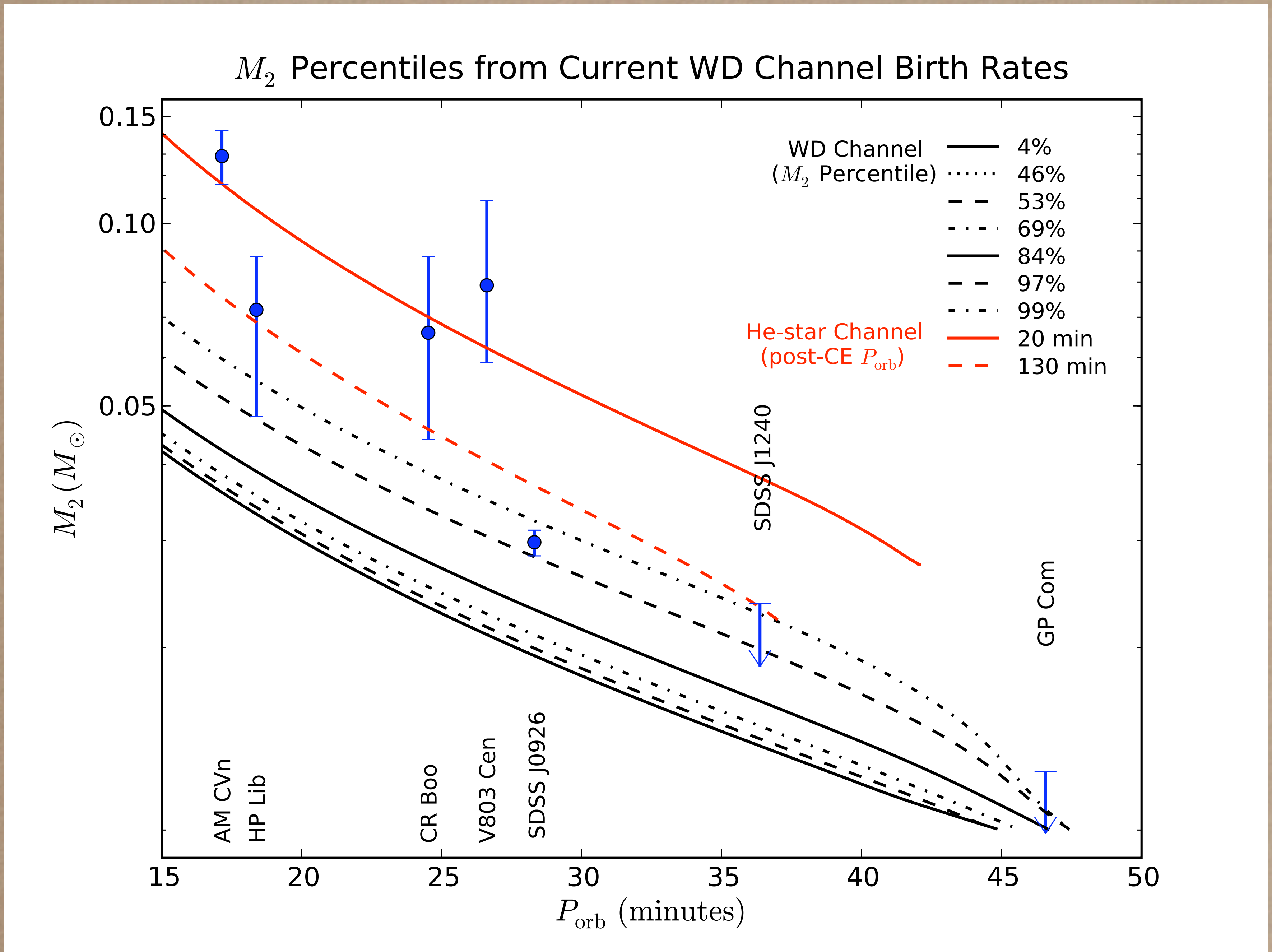

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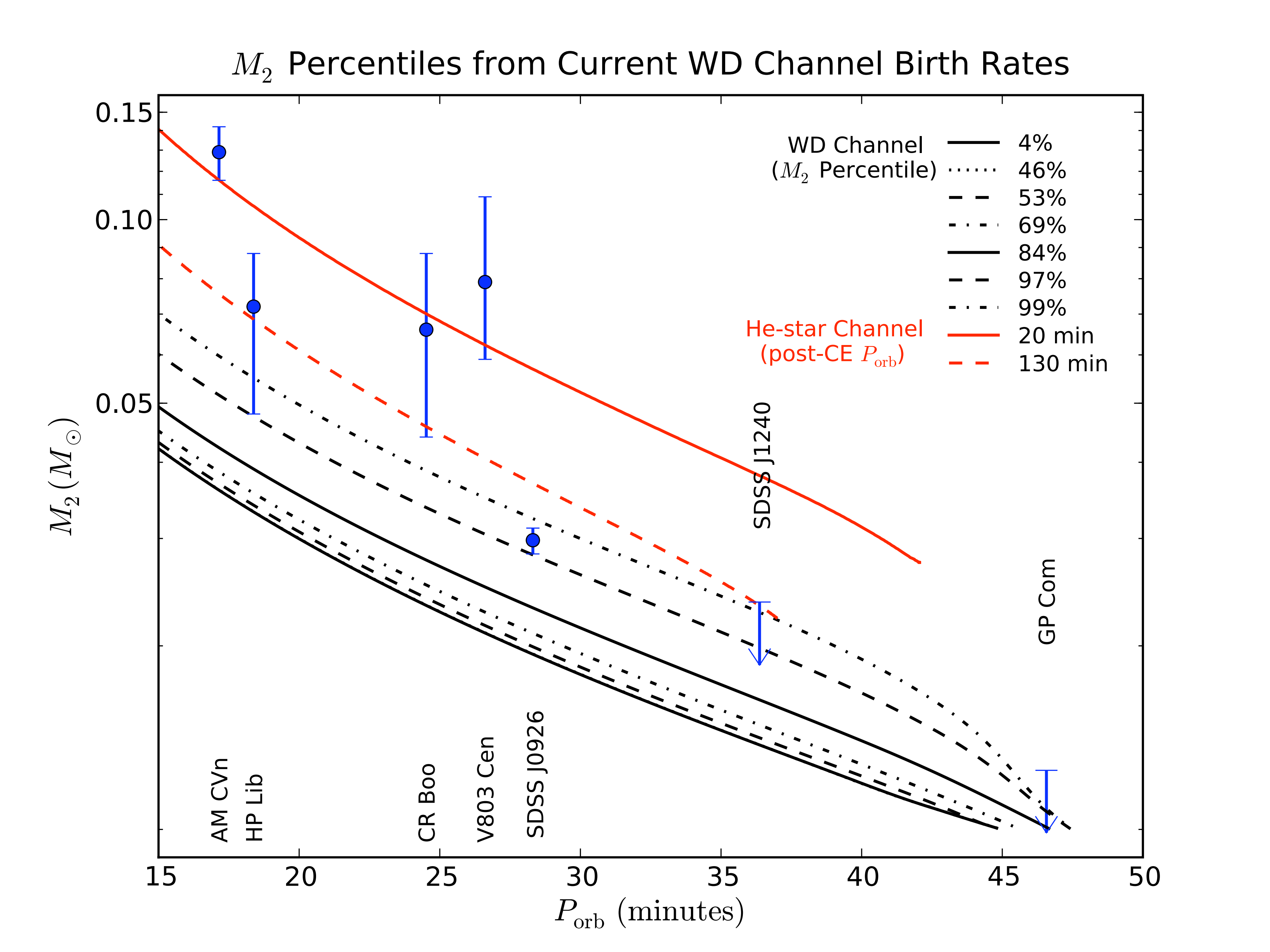

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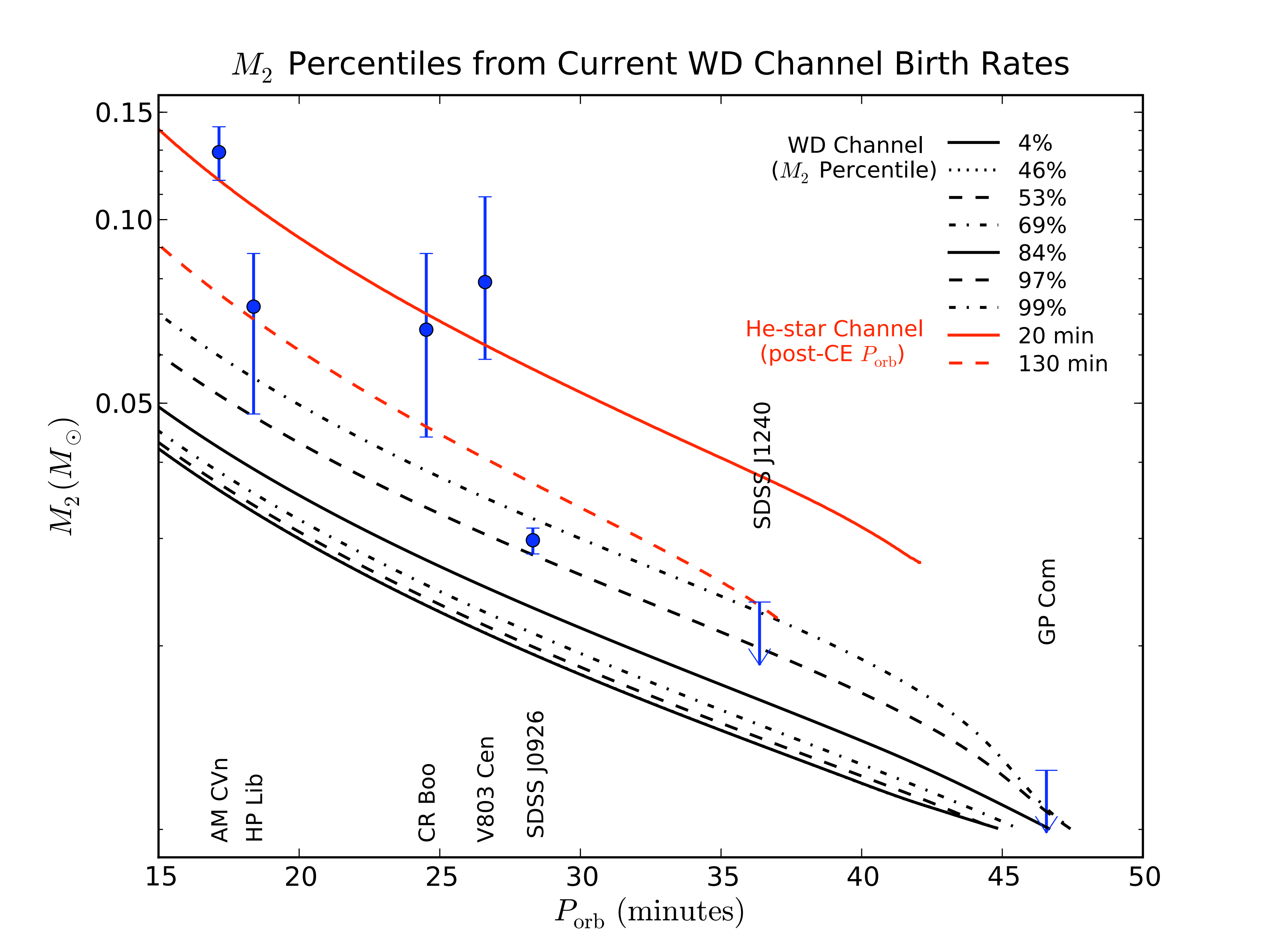

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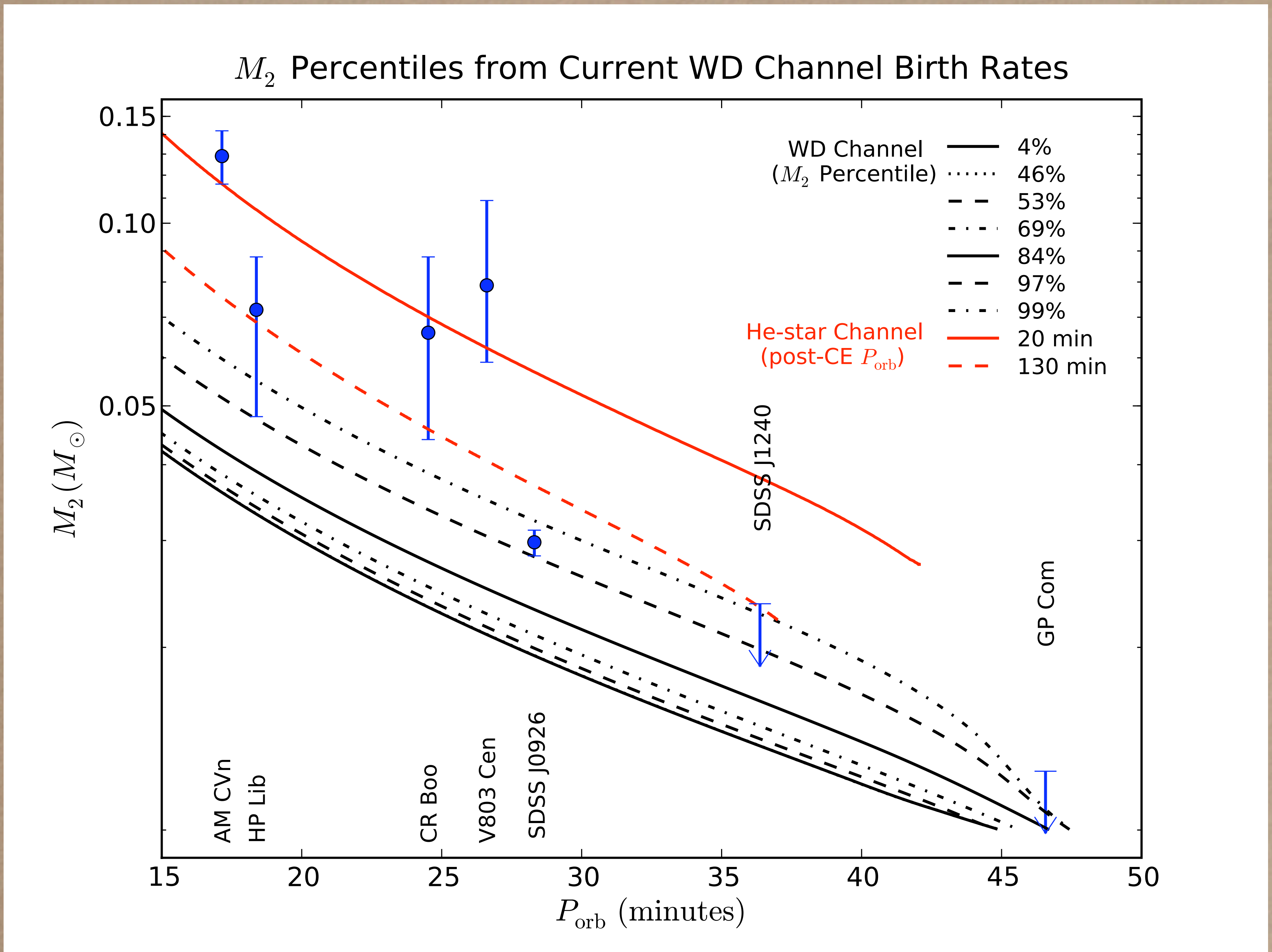

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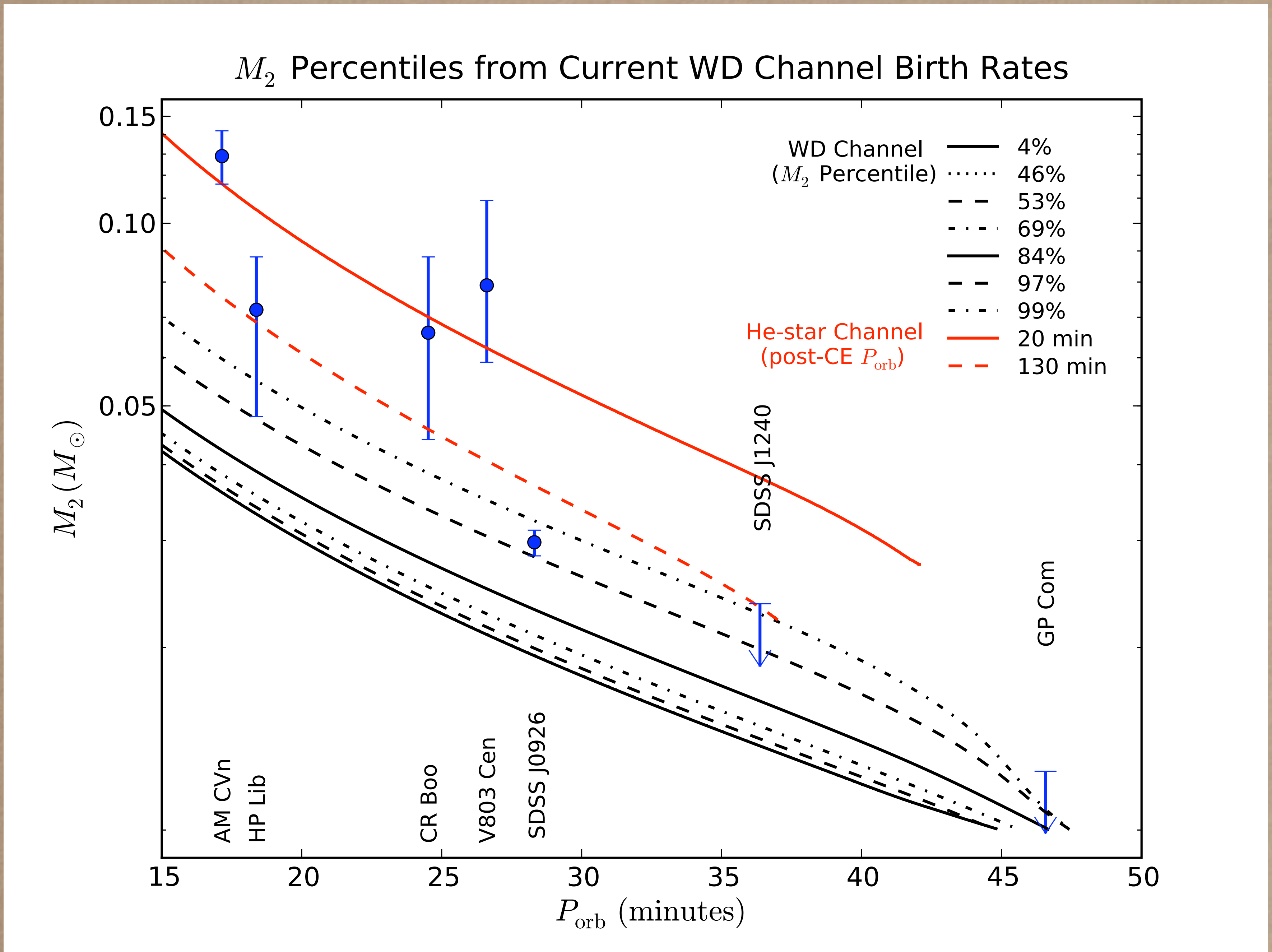

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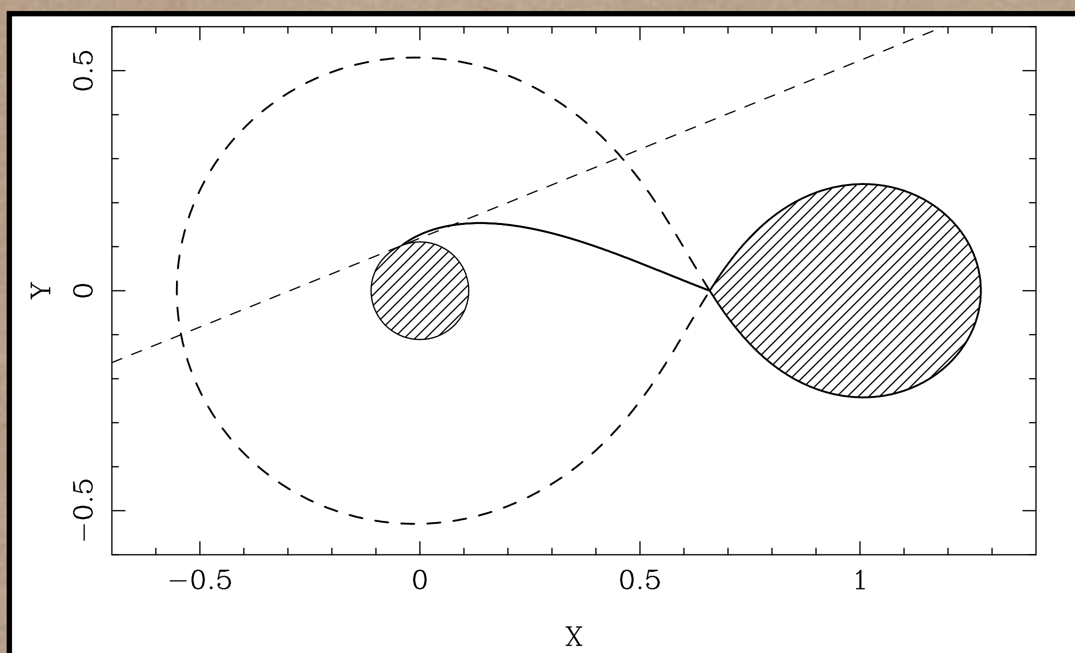
- He-star channel: are observed abundances consistent with this channel dominating AM CVn production (Lev and Gijs N. working on this)?

Mass Transfer Stability at Contact and Direct Impact Accretion

Direct Impact Accretion:

In most cases, proto-AM CVn at contact are in so tight an orbit the accretion stream impacts the accretor directly.



(Marsh & Steeghs 2002)

Accretor spin-up provides a sink for orbital angular momentum and contributes to the instability of mass transfer.

Stability Criteria:

(in absence of efficient tidal torques.)

$$\Rightarrow q < \frac{5}{6} + \frac{\xi_2}{2} - \sqrt{(1+q)r_h}$$

$$q \equiv \frac{M_2}{M_1} \qquad \xi_2 = \frac{d\ln R_2}{d\ln M_2}$$

r_h : *parameterizes J lost in accreted mattter.*

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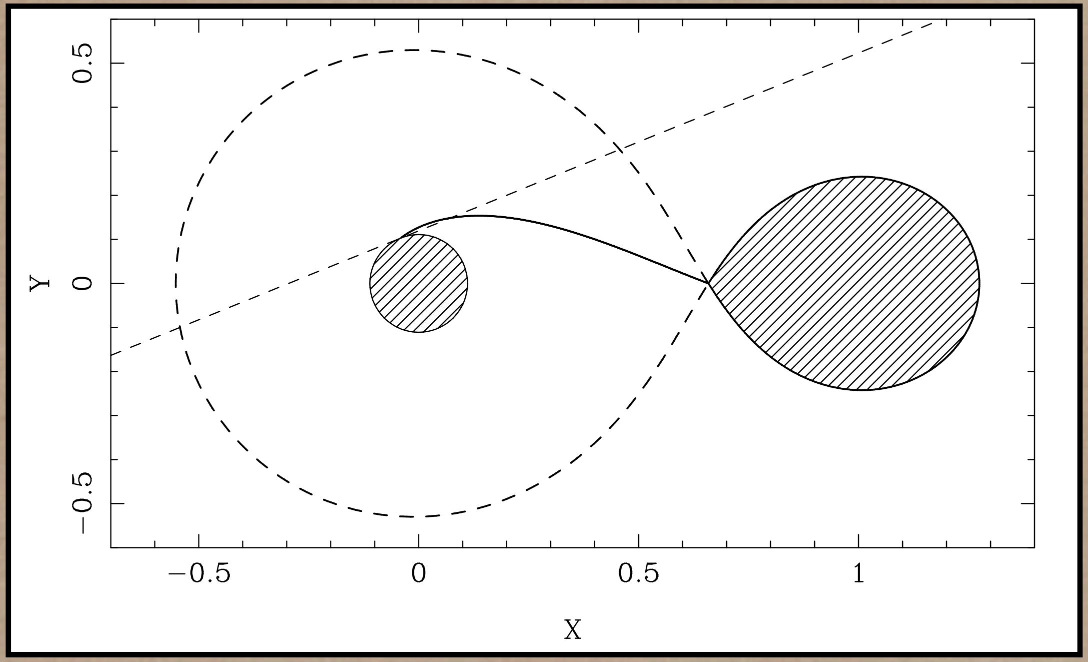

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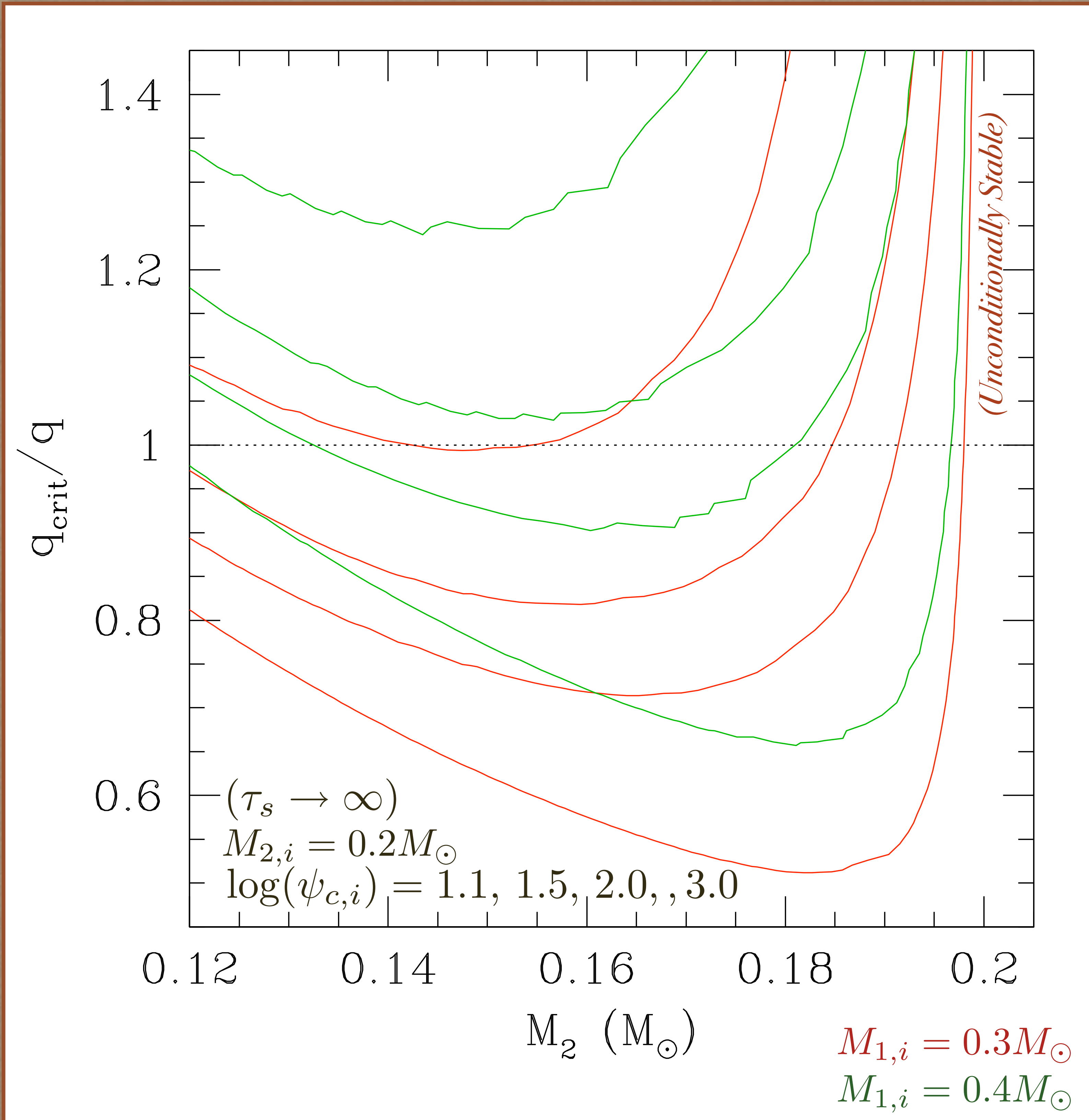
For fully degenerate donors, DI accretion produces unstable mass transfer in vast majority of WD Channel systems (*in absence of efficient tidal coupling*).

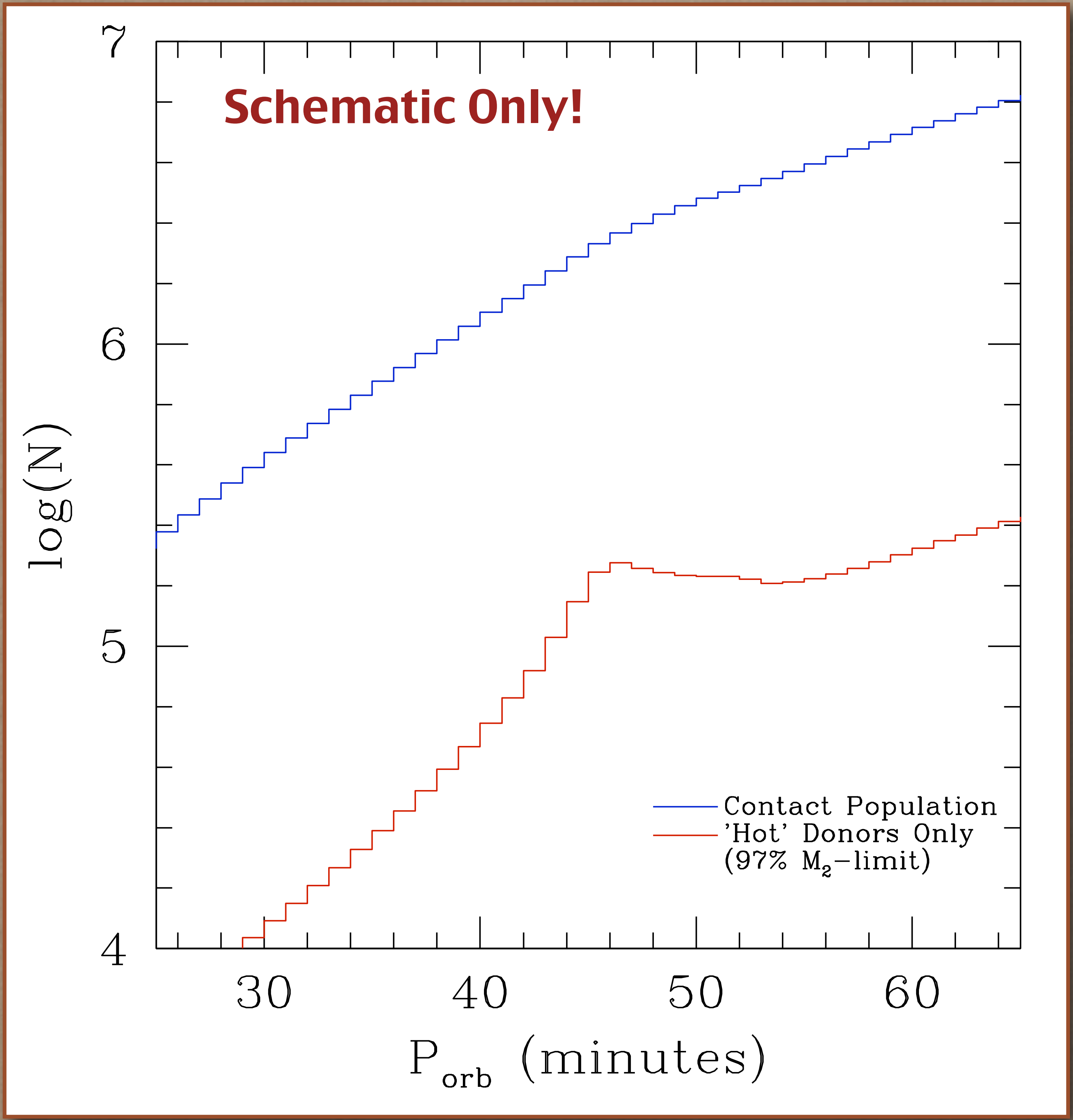
(Nelemans et al. 2001, Marsh et al 2004)

Direct Impact Accretion: Hot Donors and Stability



- Hotter donors have larger minimum ξ_2.
- Stable DIA occurs preferentially for
  - high entropy donors.
  - massive accretors.
- Reason for no cold donors?!?!
  - Caveats, caveats, caveats:
    - Tidal coupling efficiency
    - Impact of tidal heating in donor (Gijs R. working on this!)
    - Is survival rate consistent with $\lesssim$10% required by observed space density.
- (Probably) can not explain the hottest observed donors.

Further Diagnostics: Long-Period System Distribution



- Late time donor cooling slows P_{orb} evolution while donor contracts.
- Imprint depends on distribution of
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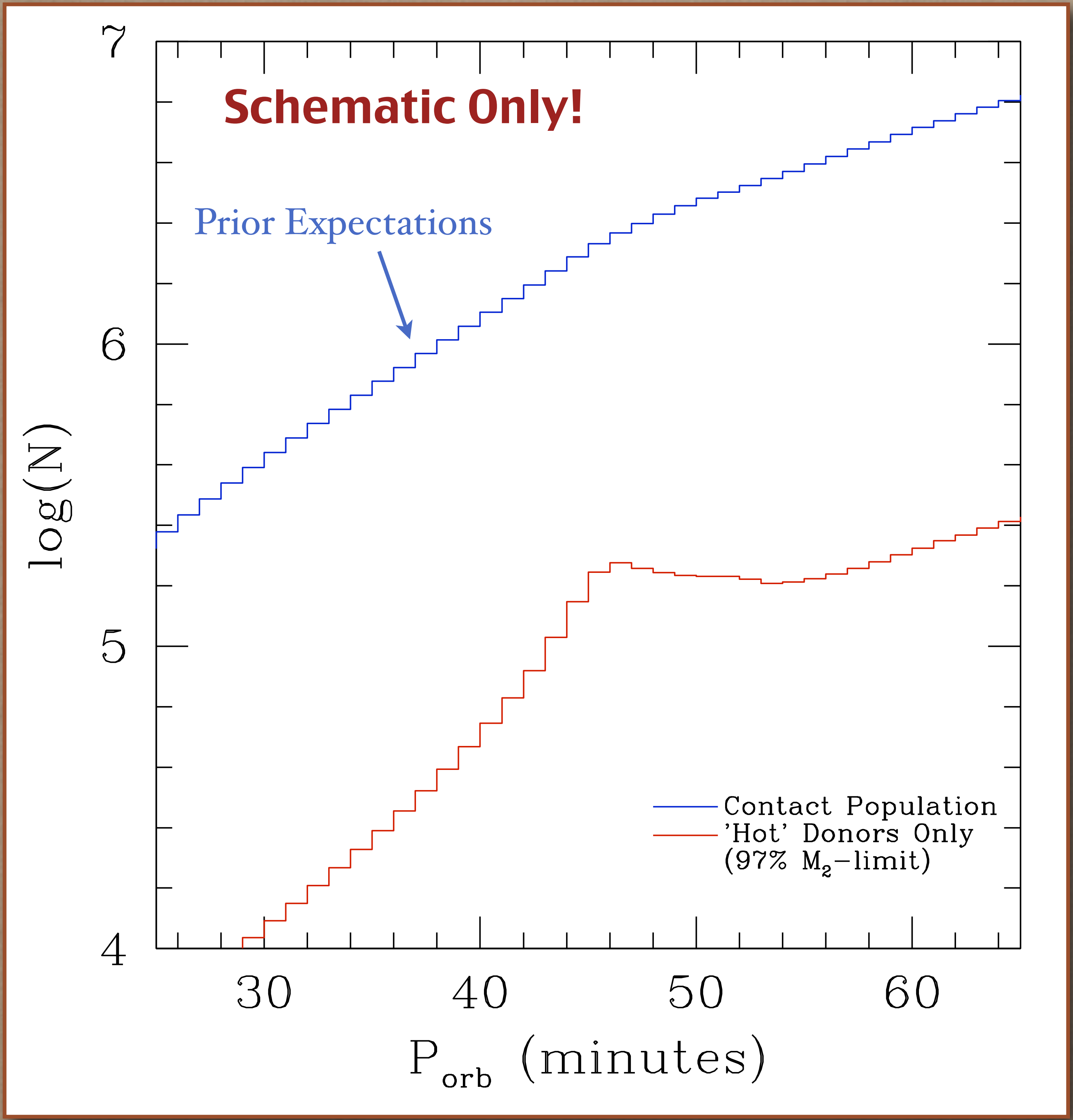

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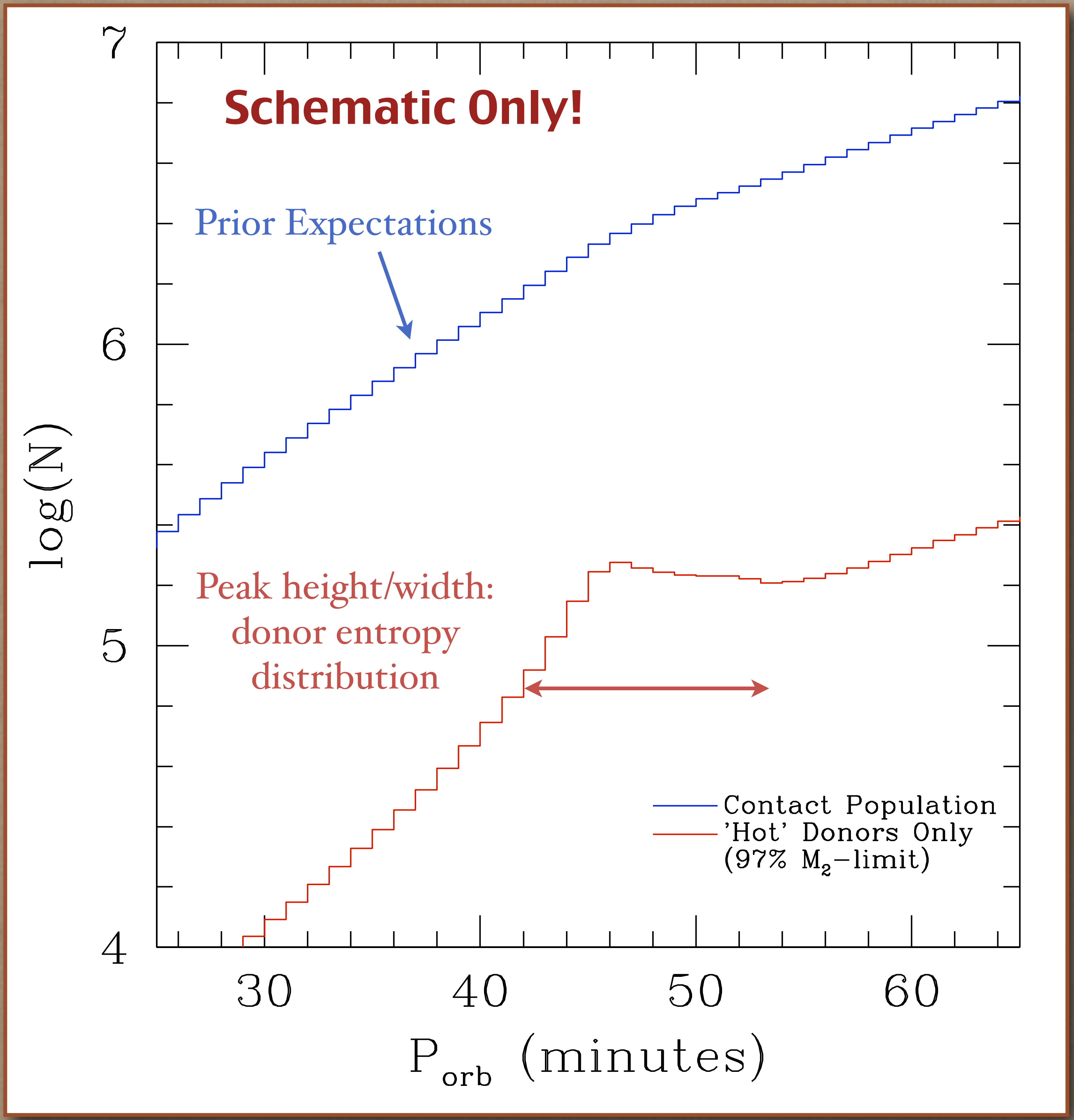

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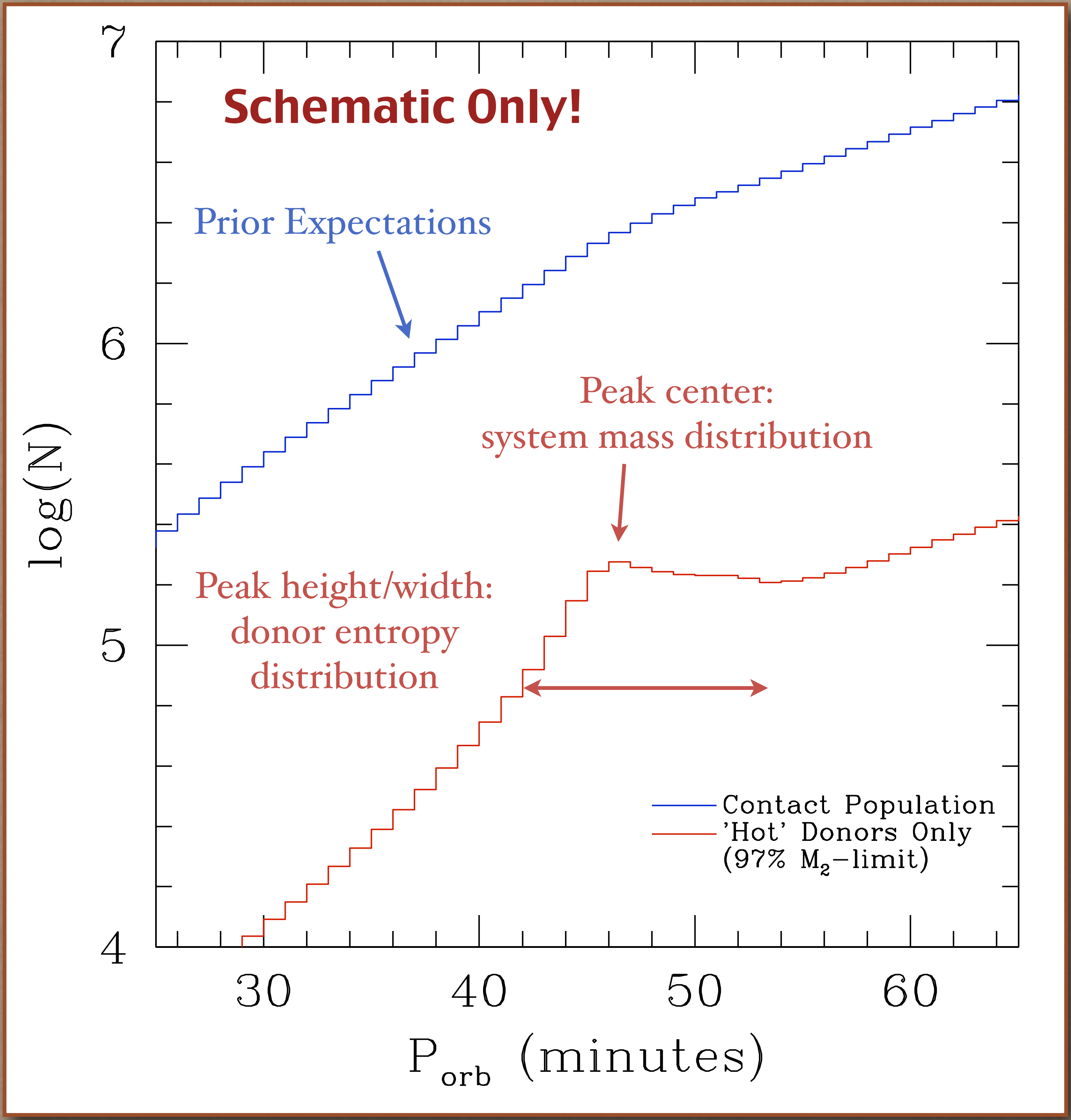

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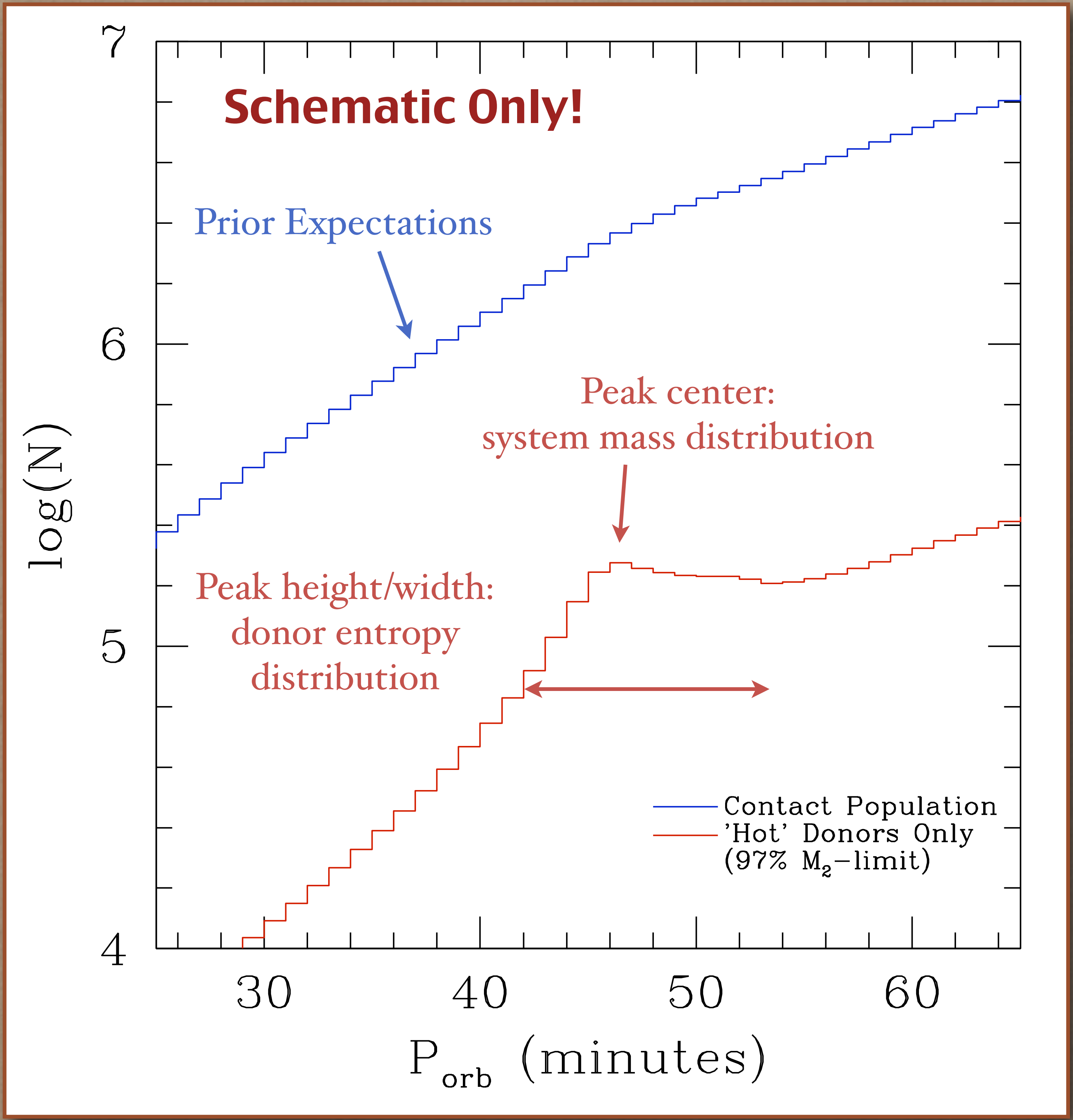

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- Imprint depends on distribution of
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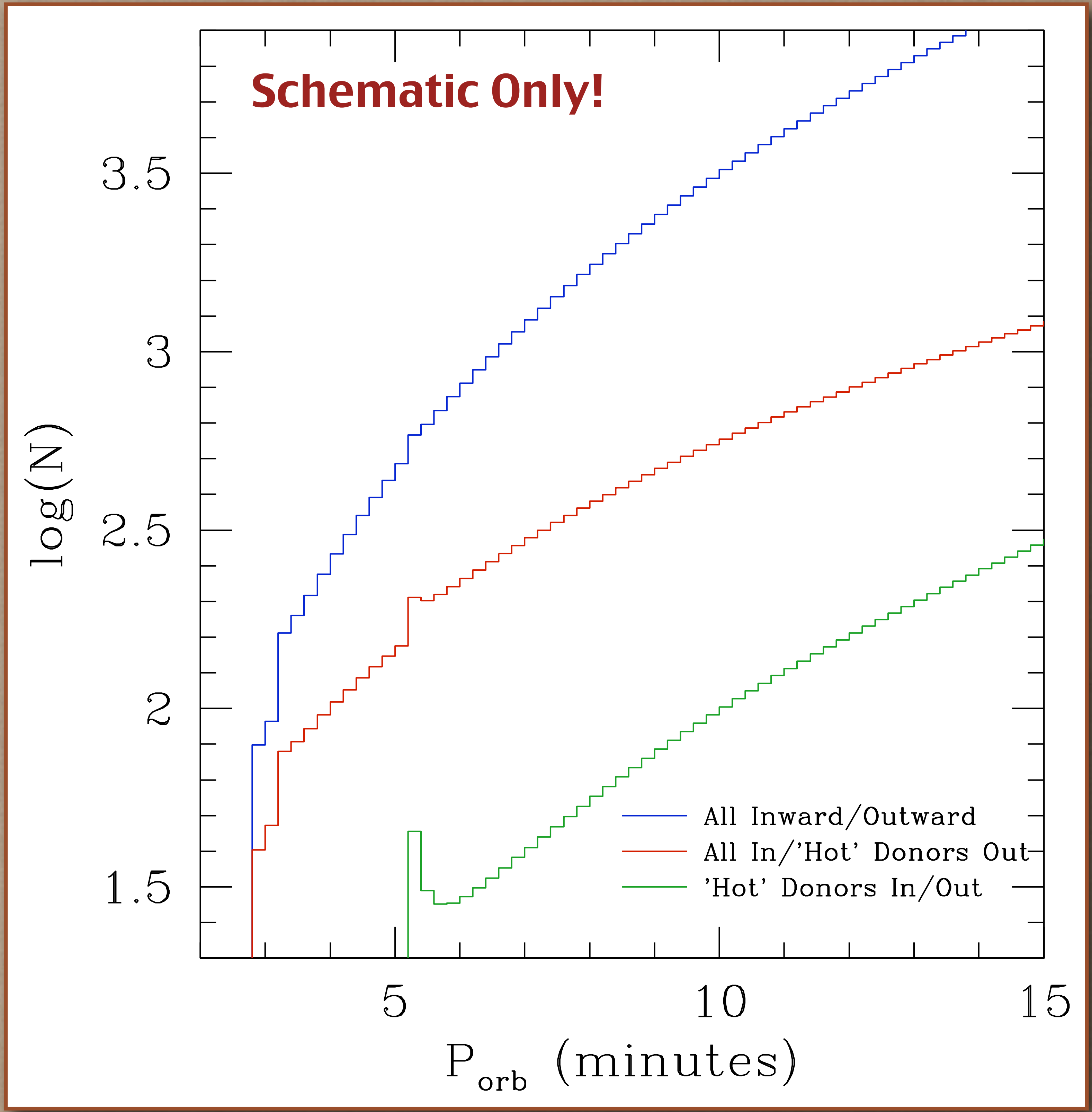
  - system masses
- Results from EGAPS (other Galatic-plane surveys??) could be *extremely* relevant/important here.
  - Survey results should allow independent determination of distribution of above properties.

Further Diagnostics: *LISA*-Era Short-Period System Distribution

- System distribution near P_{orb}-minima provides information on
  - post-CE donor states
  - which systems survive contact.



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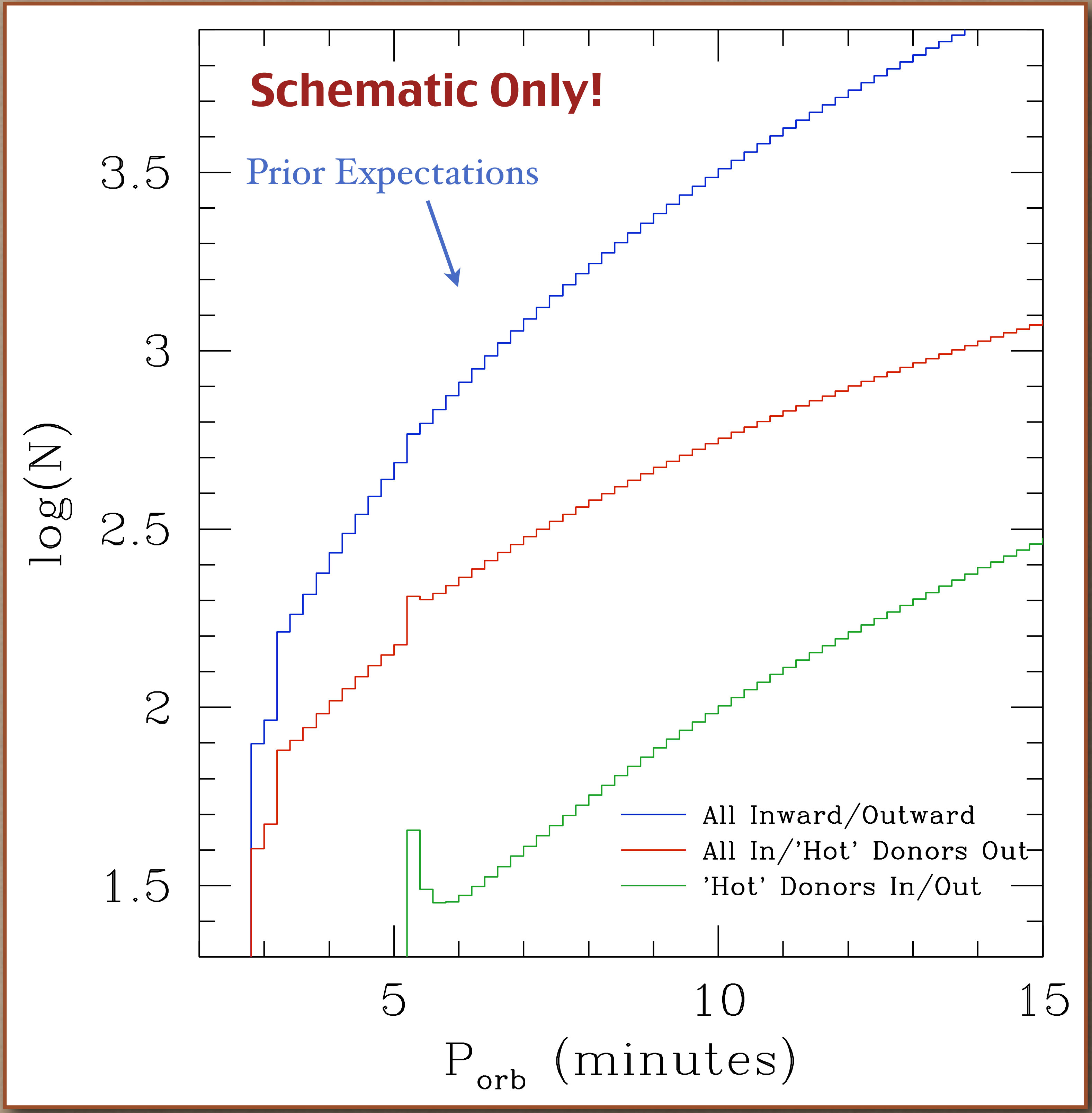

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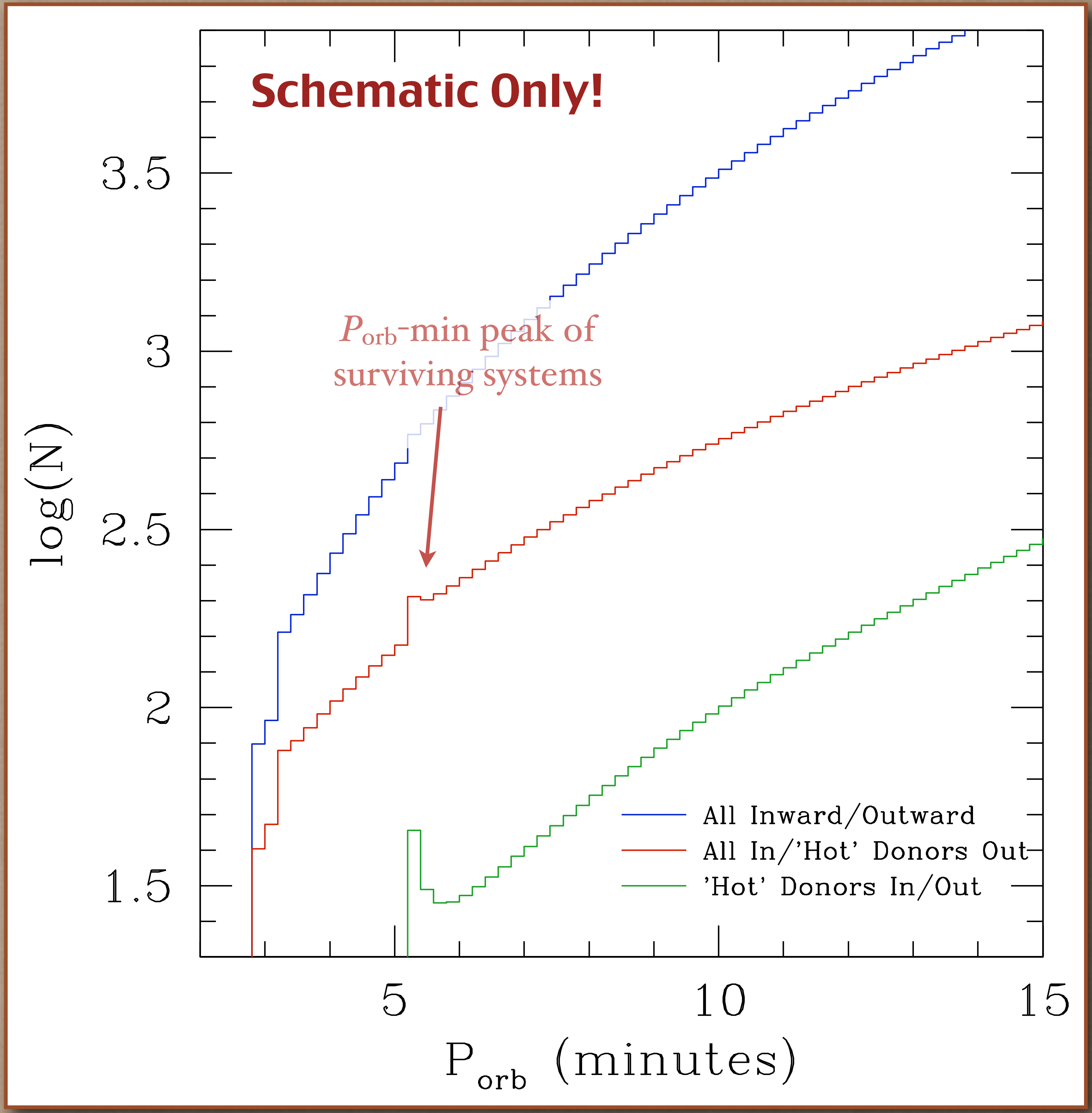

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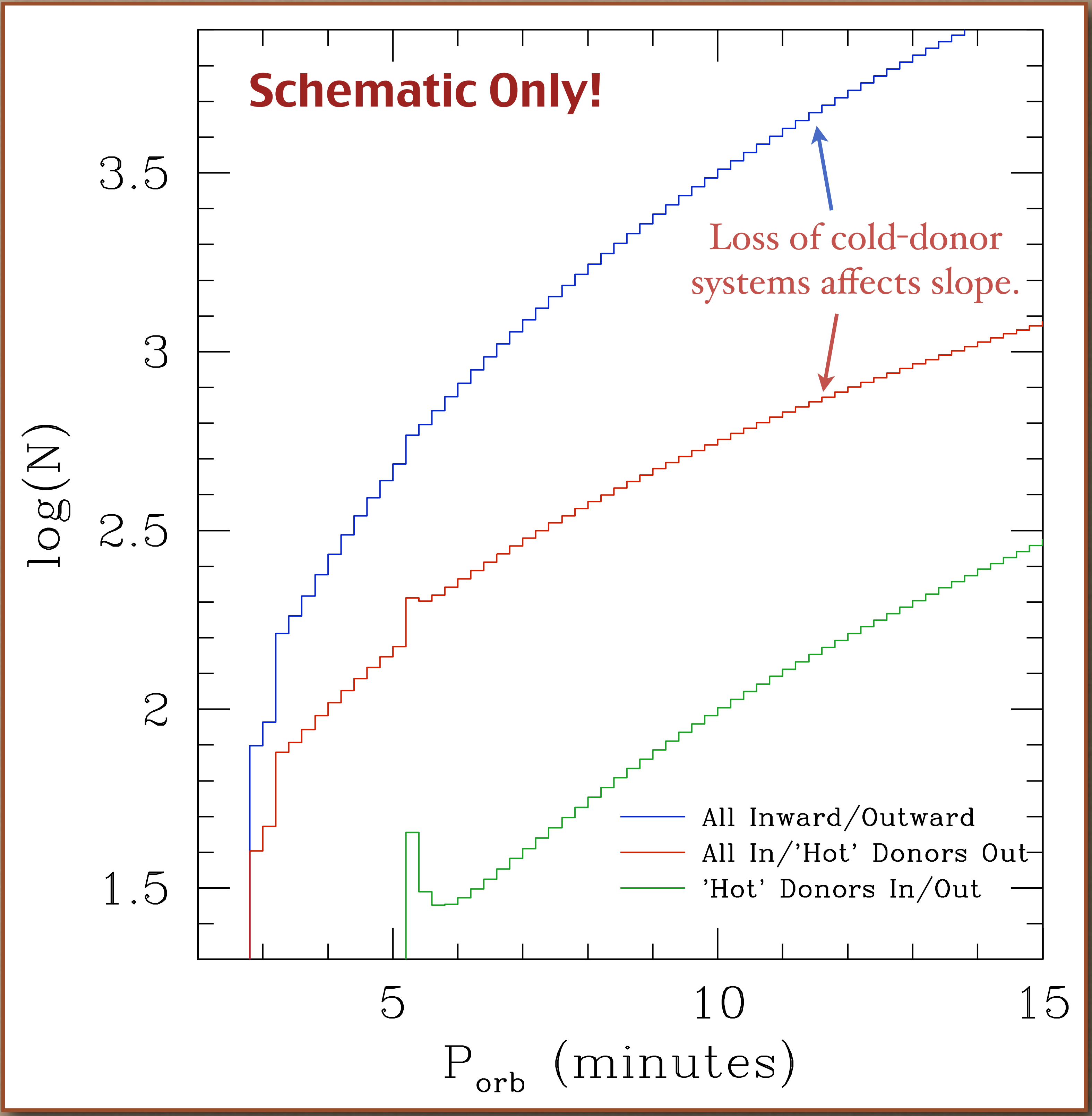

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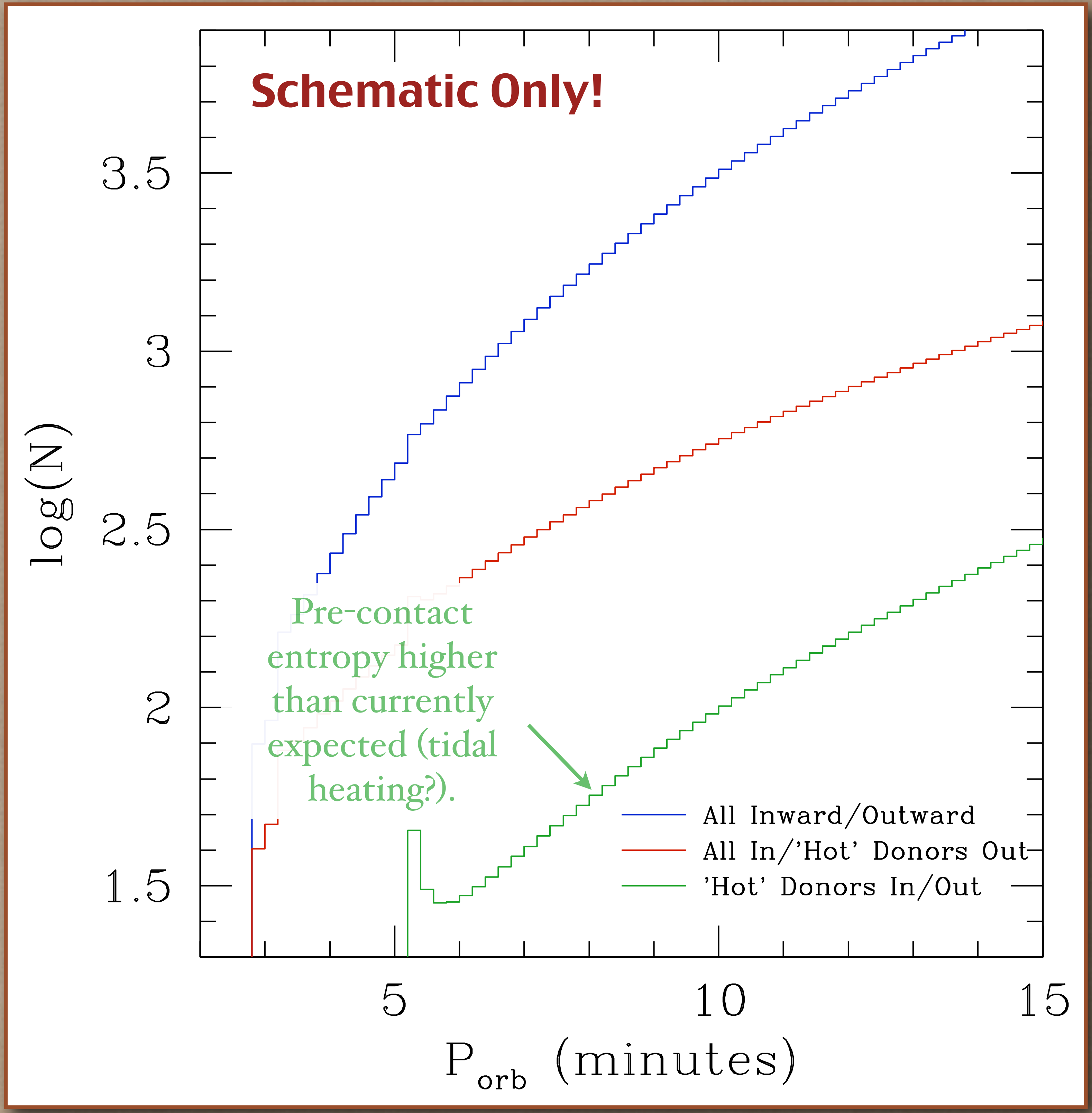

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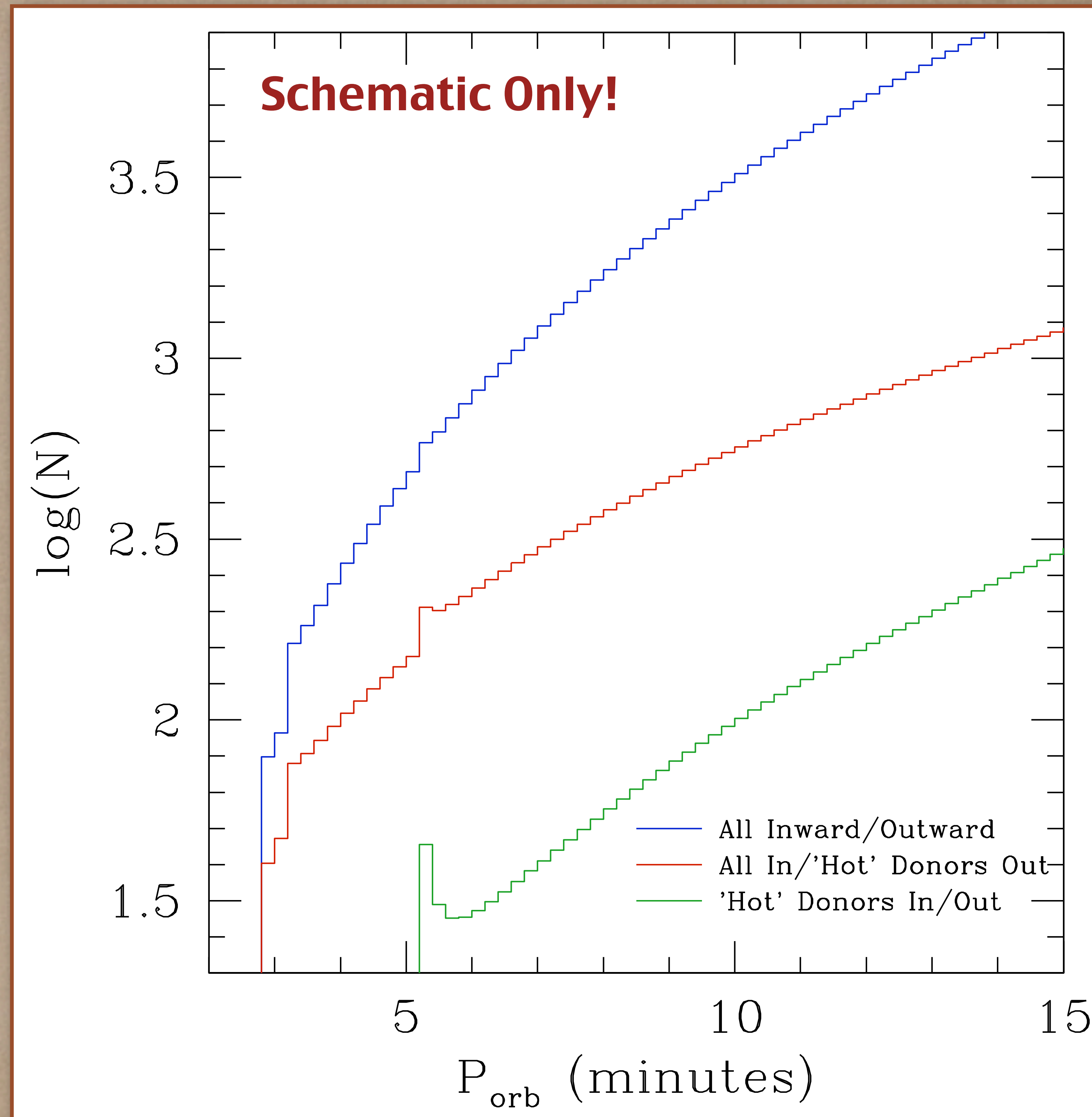

Further Diagnostics: *LISA*-Era Short-Period System Distribution

- System distribution near P_{orb}-minima provides information on
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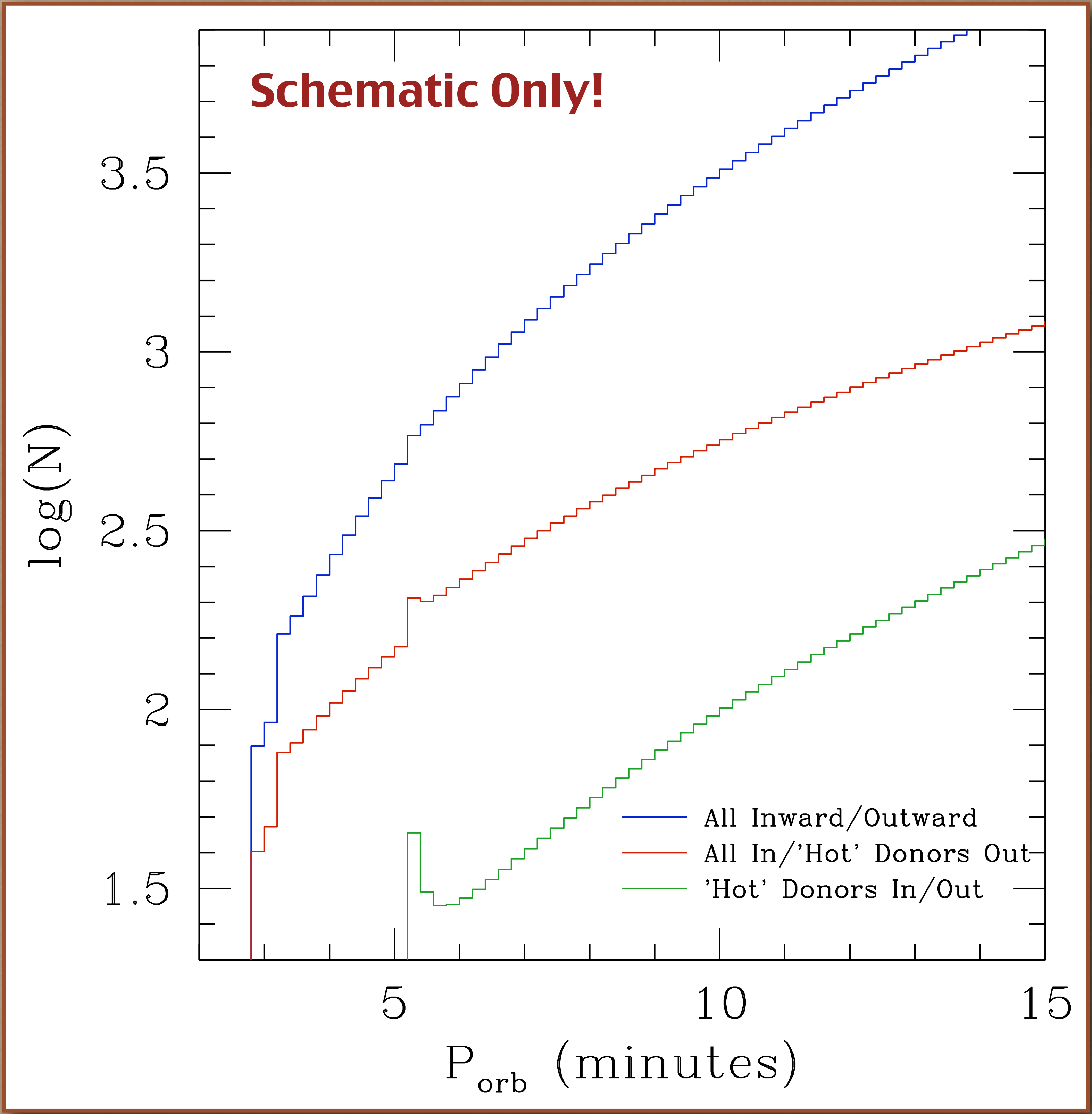

Further Diagnostics: *LISA*-Era Short-Period System Distribution

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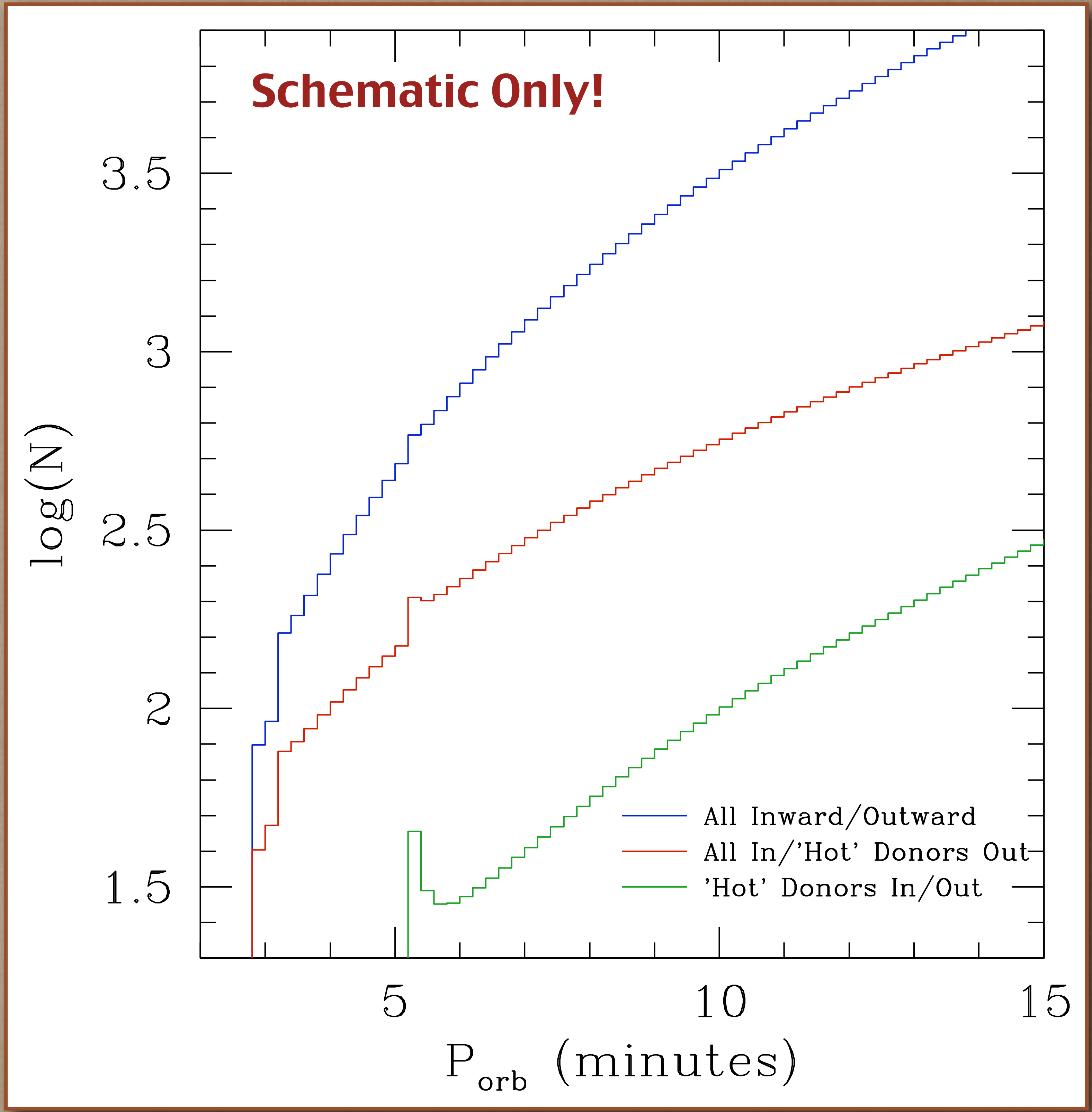
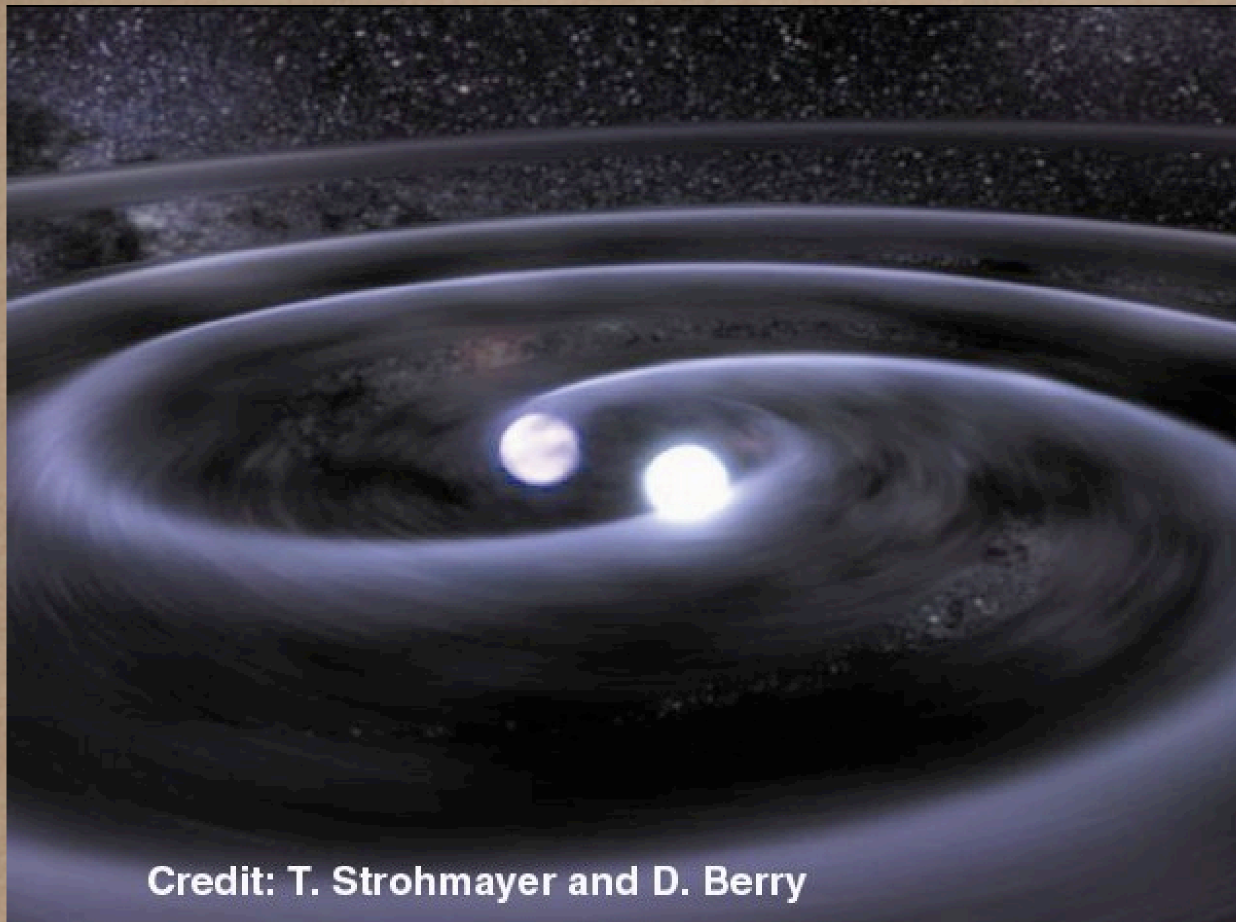
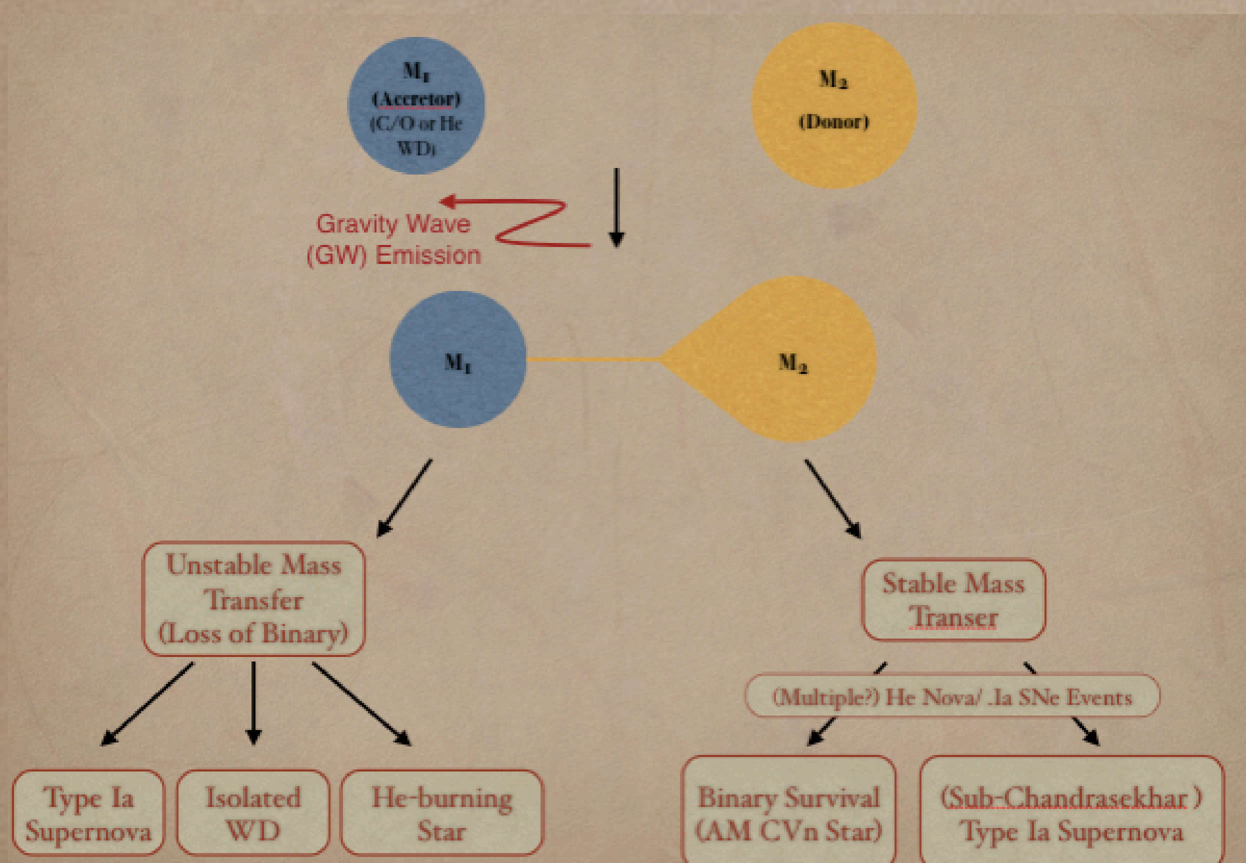
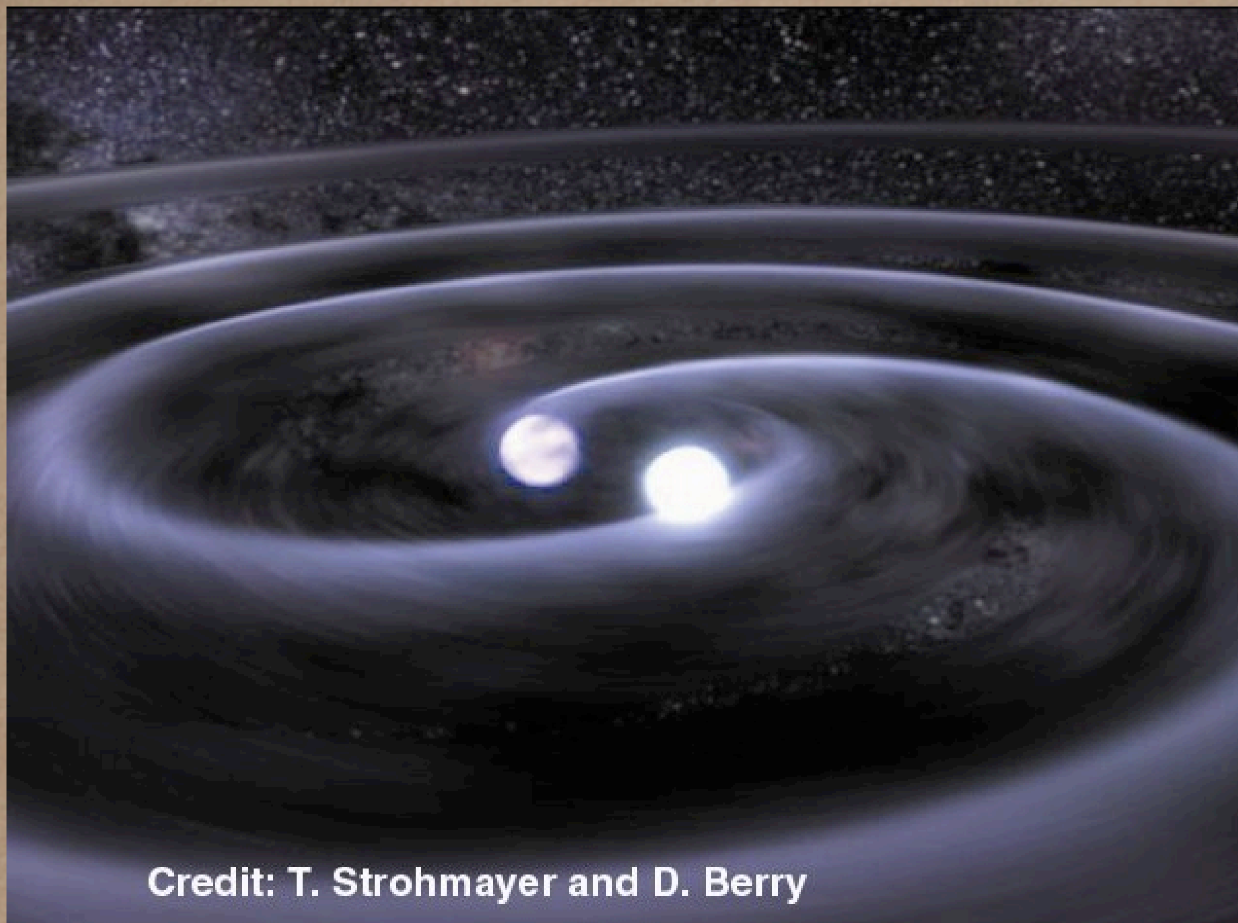
- Are the donors hot at contact or are cold-donor systems filtered-out at contact?
  - Implications for CE physics and pre-contact system evolution.
  - *LISA* could provide a definitive answer to this question.
  - In the meantime …



The Big Picture.....

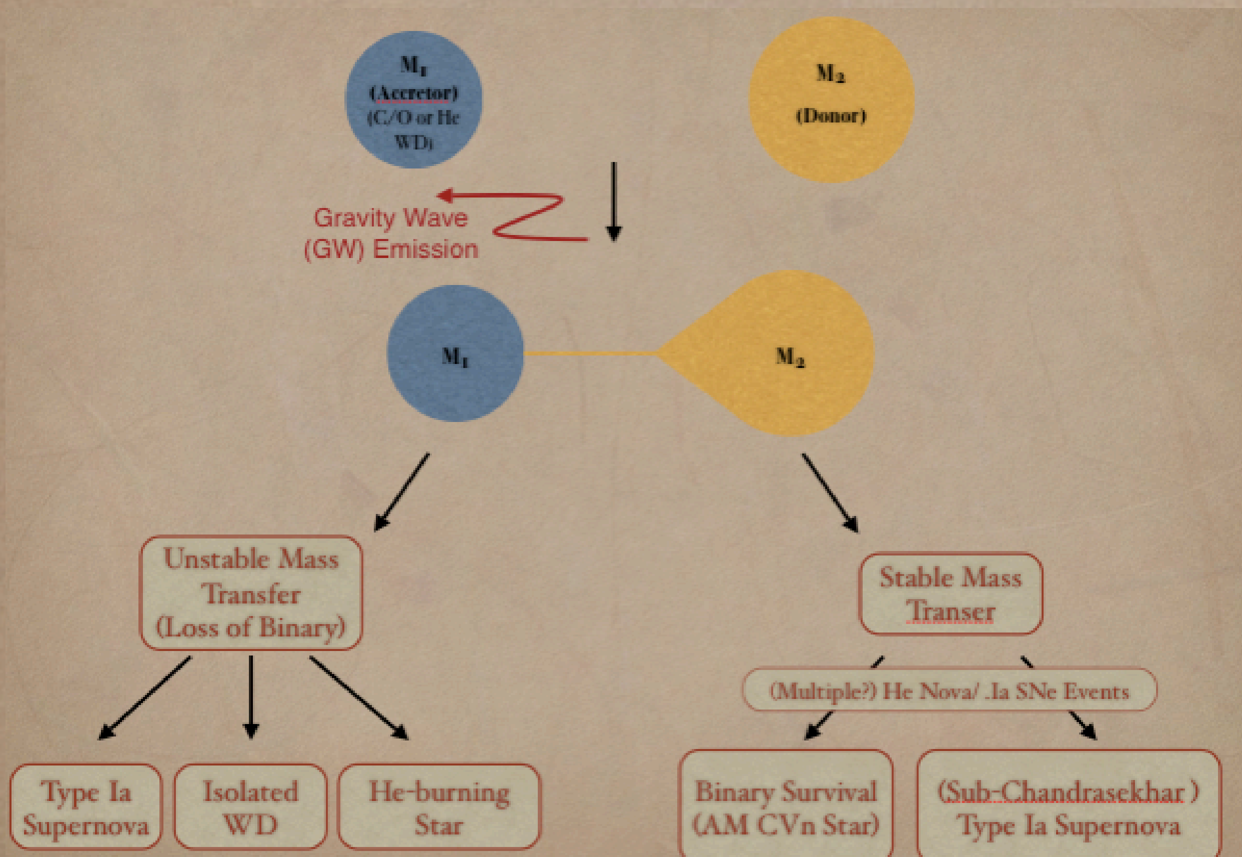


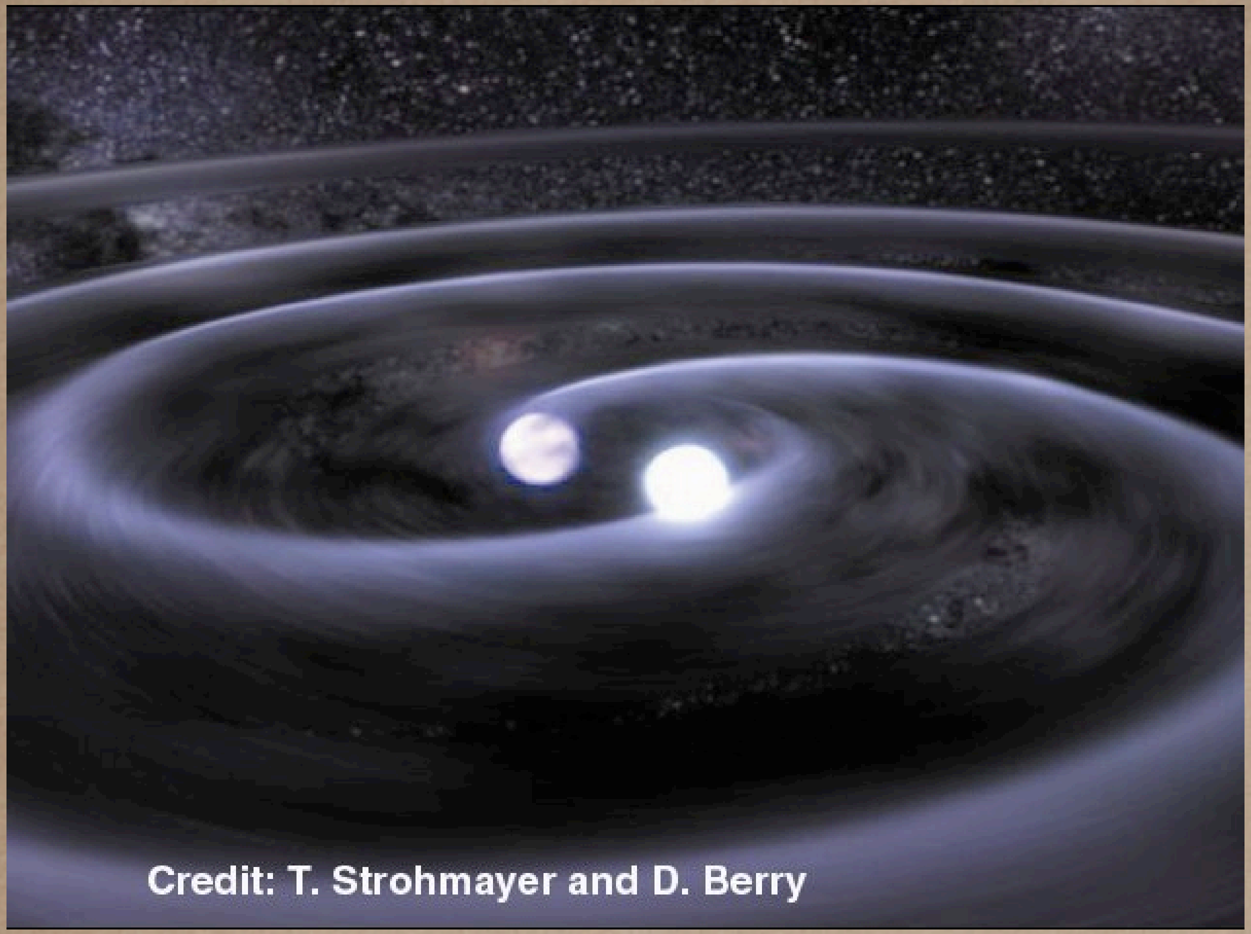




The Big Picture.....

- The AM CVn population shaped in combination by uncertain
  - binary evolution processes in prior phases
  - processes at contact
  - want to understand both!





The Big Picture.....

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- Understand how the various physical uncertainties
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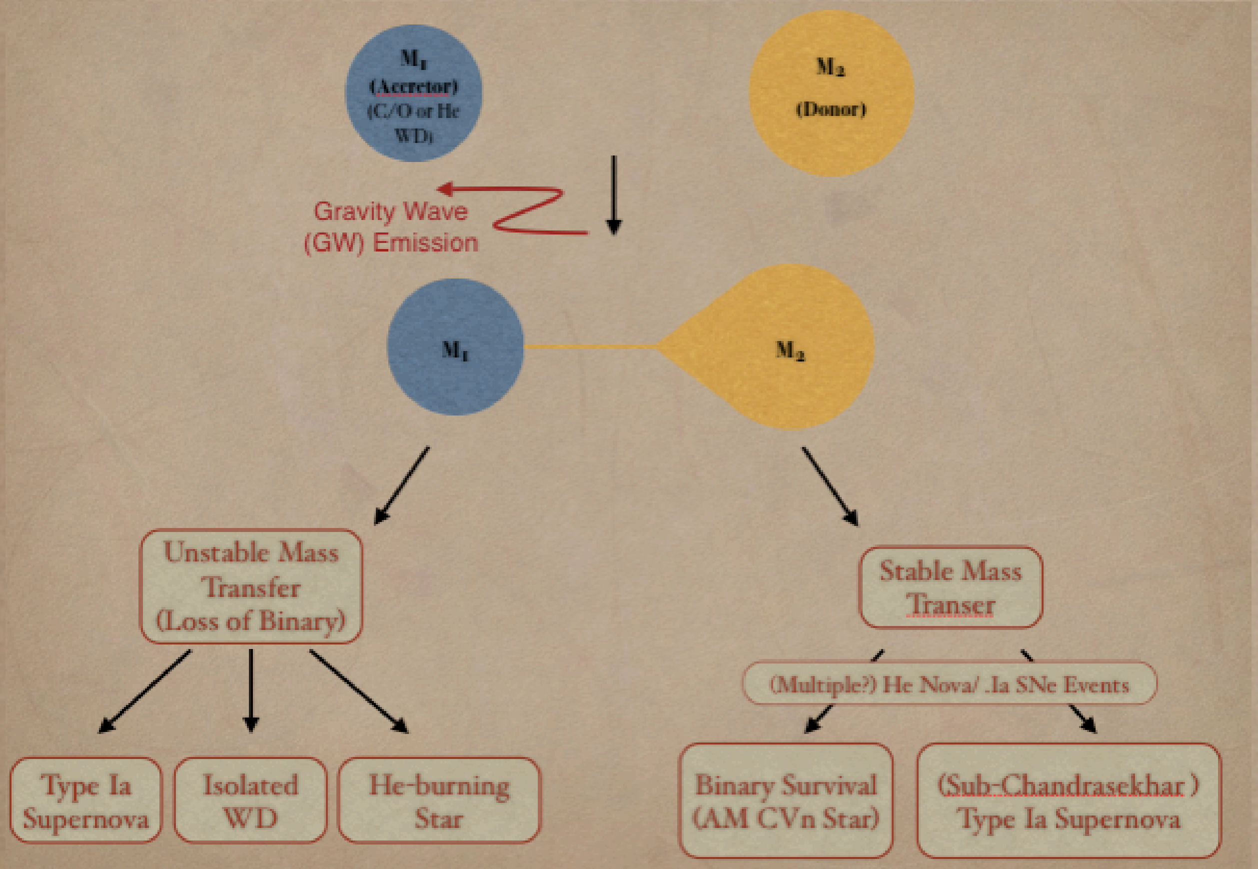

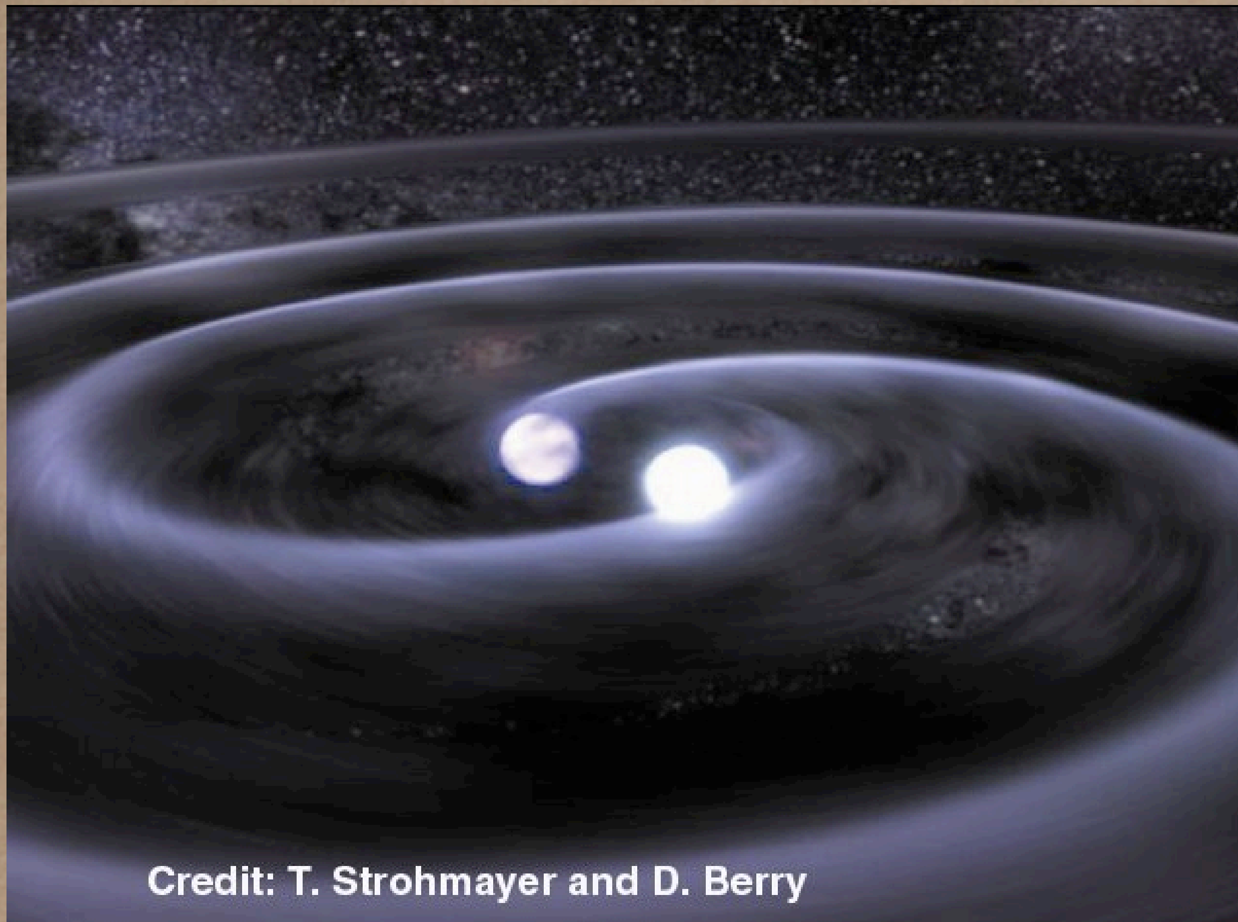

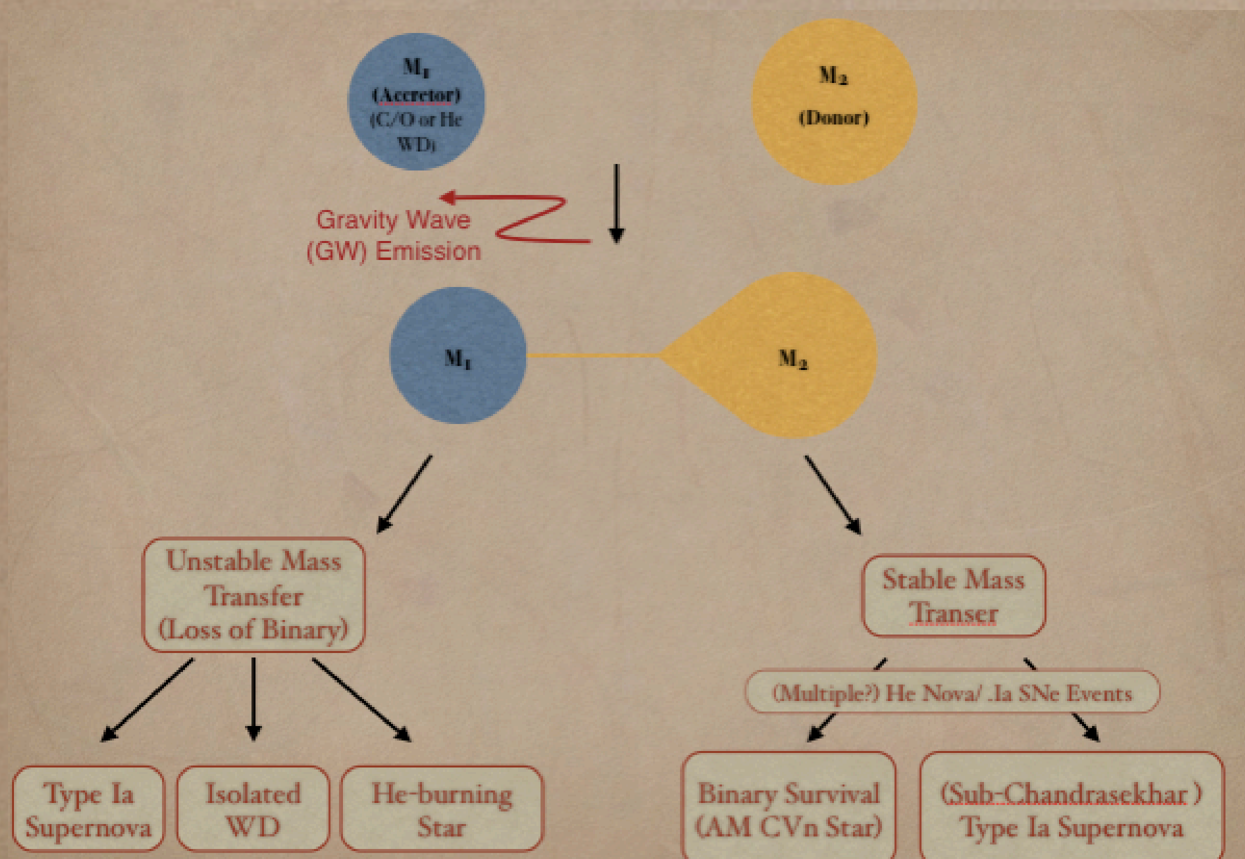

The Big Picture.....

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- Understand how the various physical uncertainties
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  - produce intermediate/alternative outcomes.
- Develop multiple, inter-related observational metrics:
  - Branching ratios between possible outcomes at contact.
  - Distribution of properties within each outcome populations.
  - Will require combination of pop synth, existing detailed models, and careful looks at interplay of multiple physics near contact.
  - Work started in this direction, but much to do.....