The Binary Evolution of BeXRBs

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with:

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Outline

- Dynamical parameters of BeXRB population
- Binary evolution mechanisms for BeXRBs
- Role of Electron Capture Supernovae
- Testable Predictions / Conclusions

- GOAL: Will try to sell a (plausible) story, as to the dynamics of BeXRB formation

Quick Overview of BeXRB Dynamics

- Be donors
- NS accretors
- Large orbital periods (30 - 200 d)
- Moderate Eccentricities

A binary evolution puzzle?

- The significant population of BeXRBs implies that the pathway which creates them is quite large (especially necessary for large BeXRB/SG-XRB ratio in SMC)

- The large orbital period suggests these systems survive relatively small natal kicks, compared to the mean NS population

A possible pathway

- 1.) A binary system with a mass ratio near unity starts in a moderately wide orbit

- 2.) The primary star overflows its Roche Lobe and stably transfers matter onto the secondary
  - If the mass ratio inverts, this widens the orbit
  - This can spin up the secondary into a Be star (Mcswain and Gies, 2005)

- 3.) The primary star supernova is underenergetic, and does not disrupt the binary system

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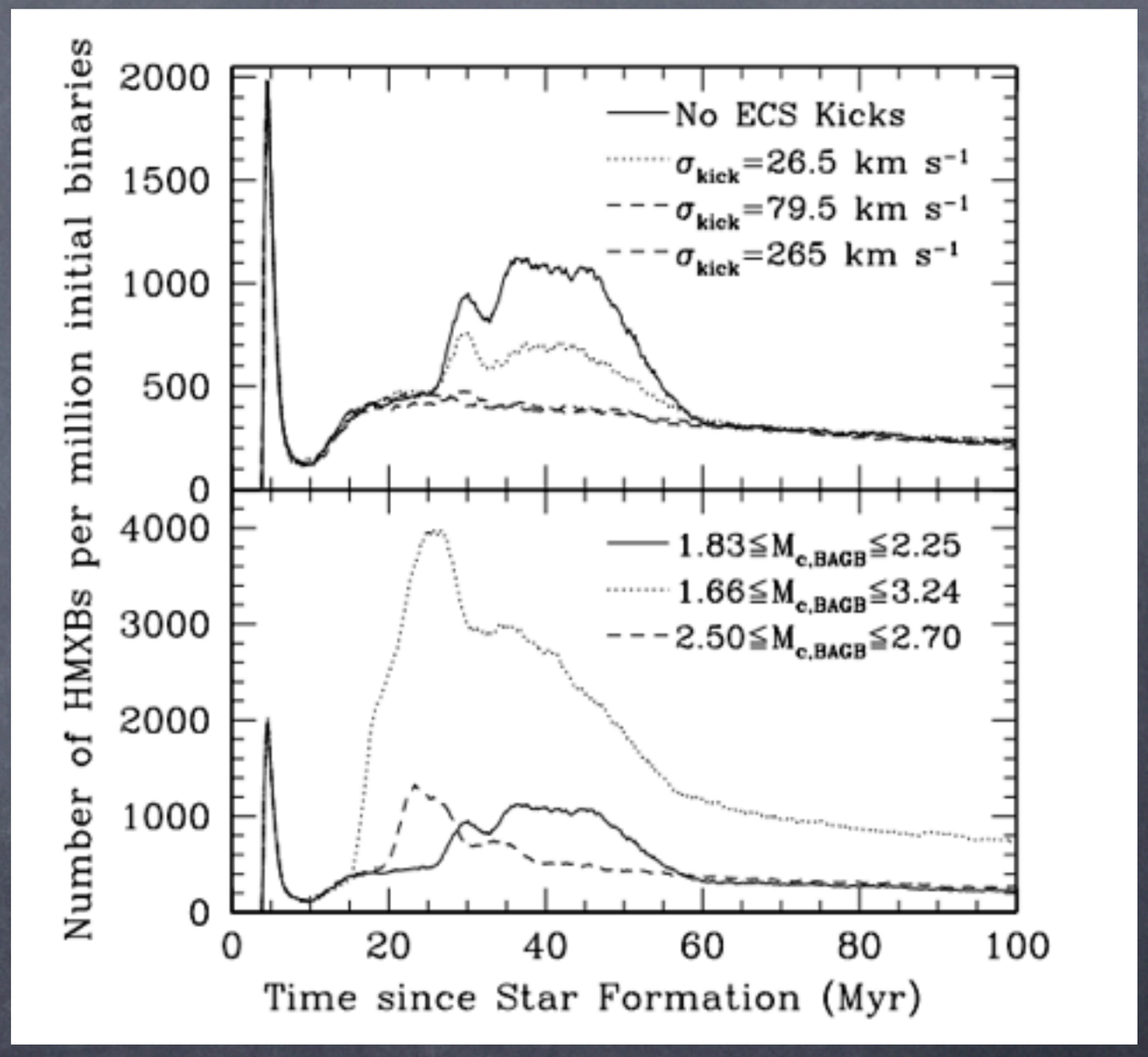
Electron Capture Supernovae

- Supernova mechanism powered by electron captures onto 24Mg and 20Ne in low mass systems ($1.83 < M_{(c, AGB)} < 2.25$) (Nomoto 1984, Hurley et al 2000, Ivanova et al 2008)
- This may translate to an initial 8-11 Msun (or larger) mass range in binary systems (Podsiadlowski 2004)
- Simulations provide SN natal kicks which are underenergetic by approximately an order of magnitude (Dessart et al. 2006)

Electron-Capture Supernovae

- ECS events naturally provide small natal kicks needed to explain BeXRBs

- Normalization depends on natal kick strength and core mass range



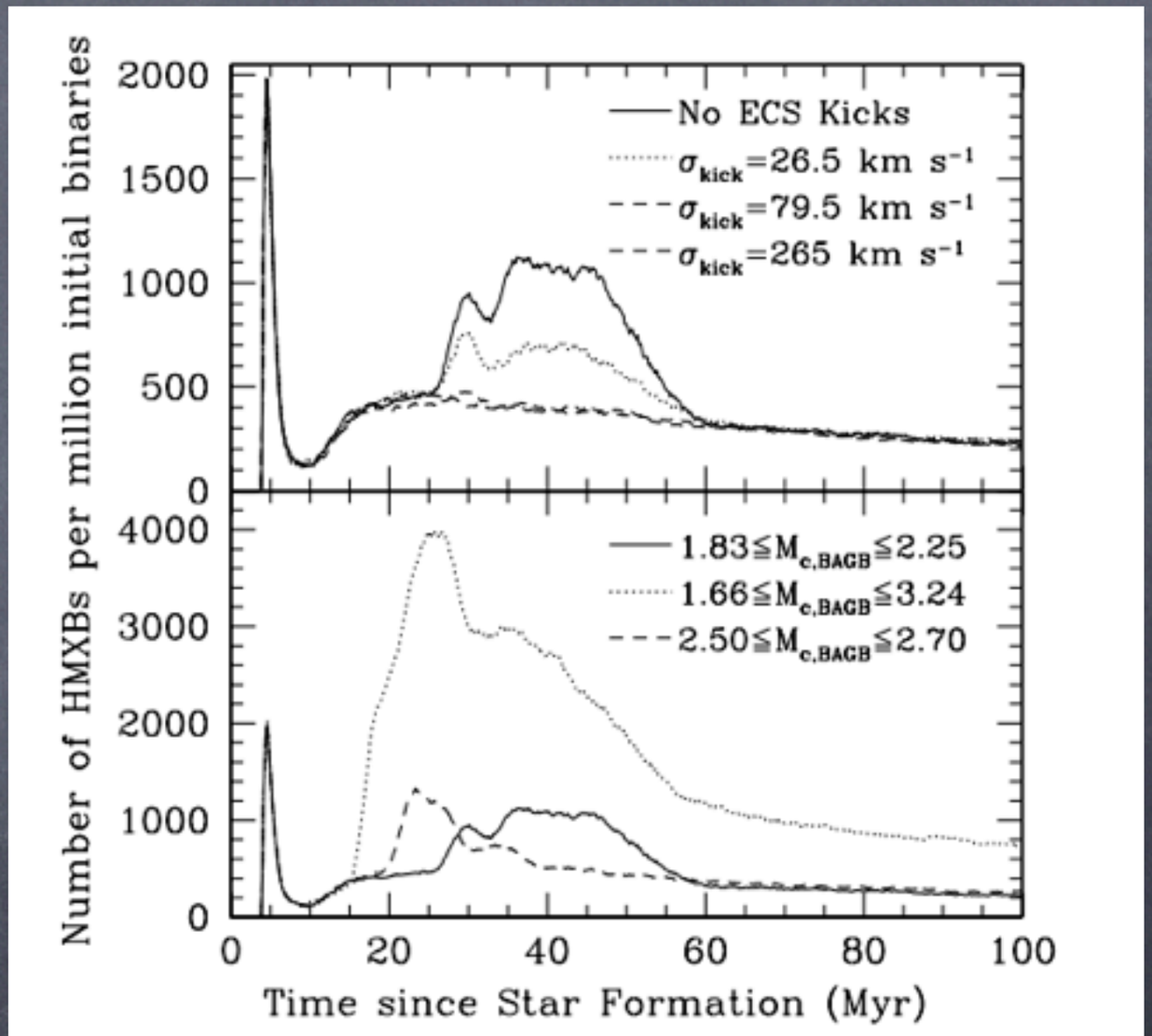
Linden, Sepinsky, Kalogera (2009)

Simulations from StarTrack (Belczynski et al. 2008)

Electron-Capture Supernovae

- The 25-55 Myr age of the ECS "bump" is coincident with the peak SFR of the SMC

- A bump here may explain the number of BeXRBs in the SMC
  (Haberl & Sasaki 2000, Majid et al. 2004, Antoniou et al. 2009)

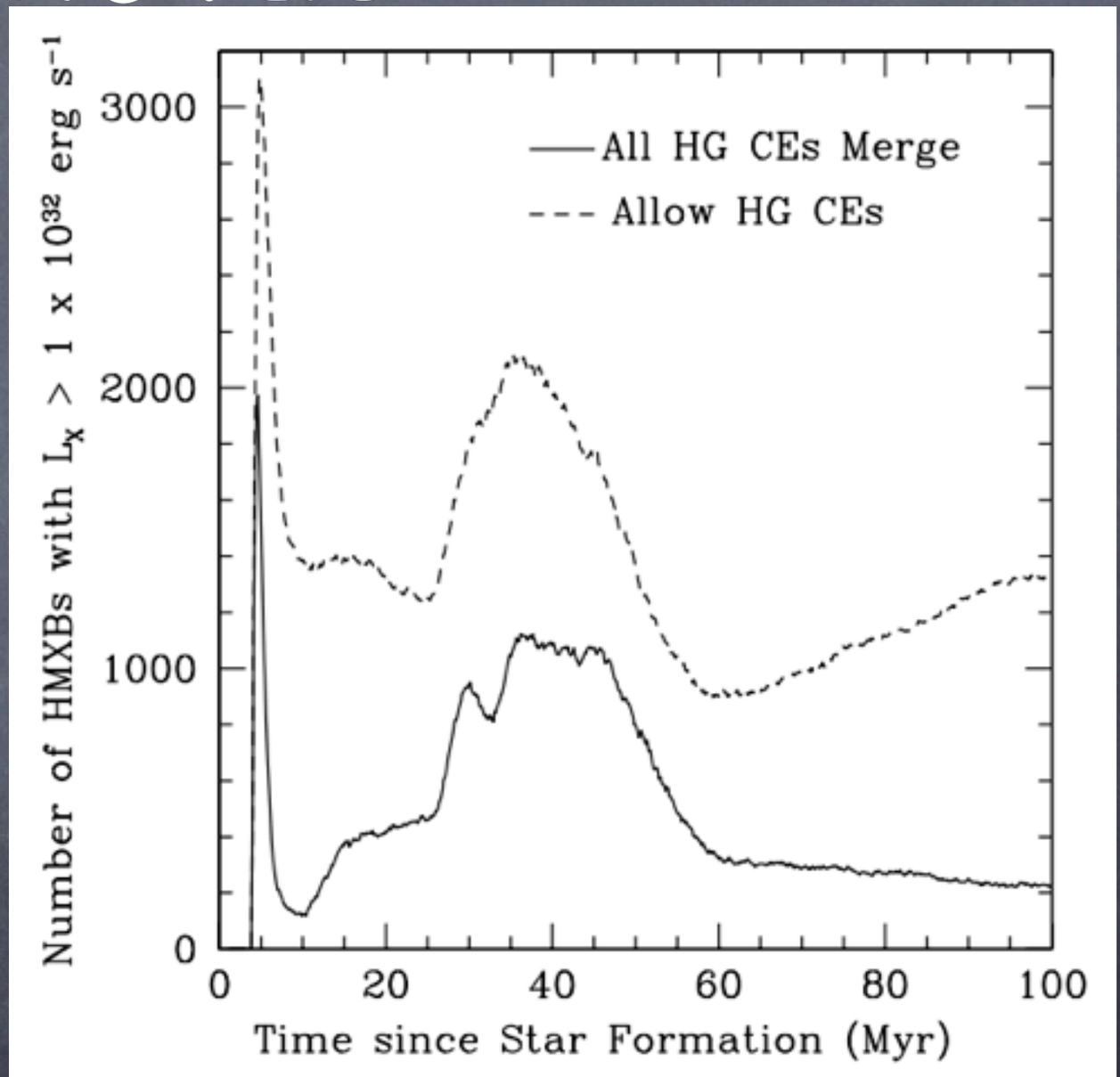


Linden, Sepinsky, Kalogera (2009)

Electron-Capture Supernovae

- HMXBs formed through ECS do not undergo CE evolution - move through mass transfer pathway

- Are resilient to changes in CE physics



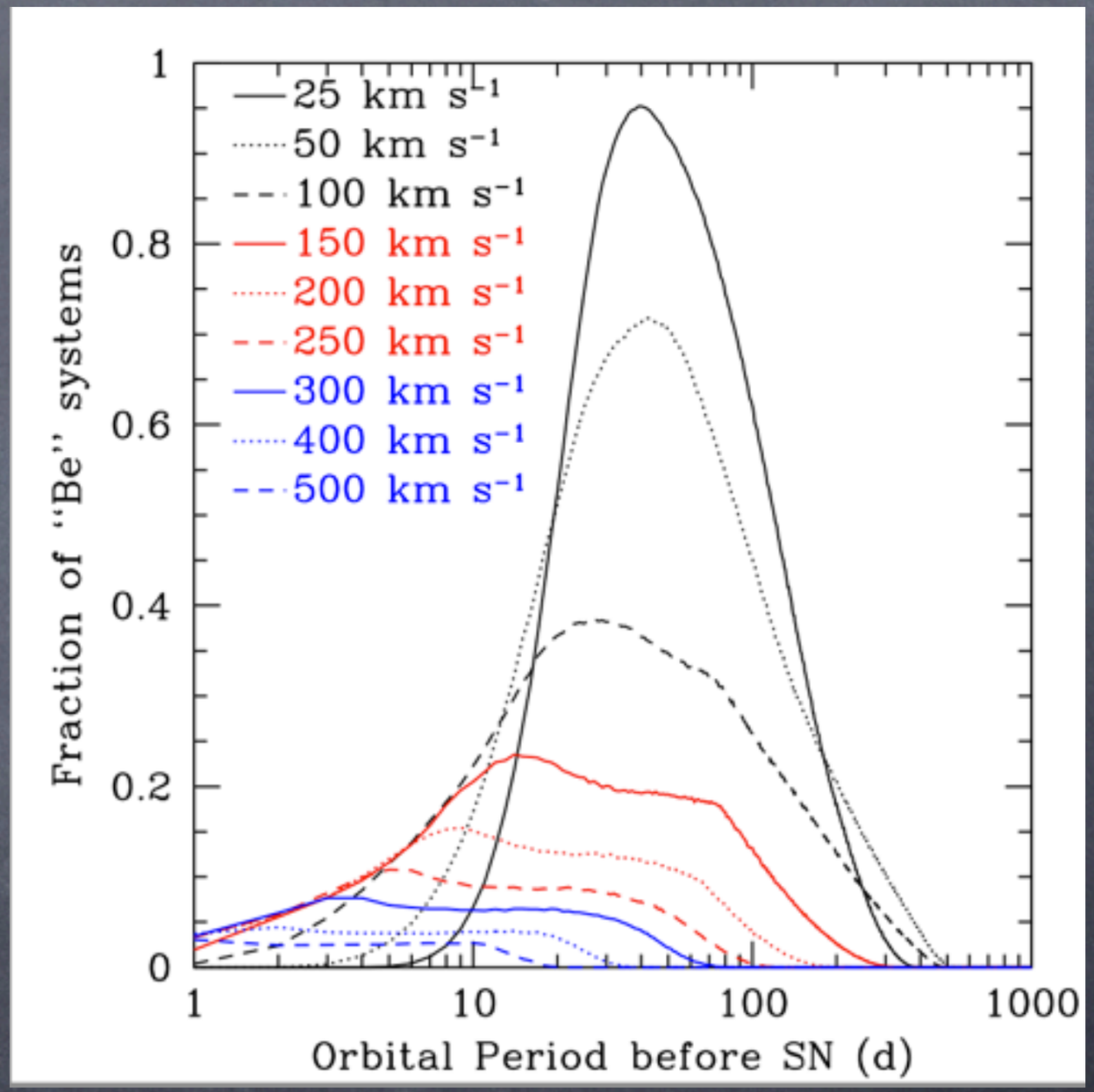
Linden, Sepinsky, Kalogera (2009)

A Toy Model of Natal Kicks and BeXRBs

- Assume that BeXRBs can form from any system with parameters:
  - Porb = 30-200 d
  - NS accretor
  - Donor mass 10-20 Msun
- Create a Monte Carlo for 10^8 natal kicks over distribution of:
  - Initial Orbital period (flat in log from 1-1000d)
  - NS progenitor mass (1.6-7.0 Msun, Hurley et al. 2002)
  - Be mass (10-20 Msun with Salpeter distribution)
  - All systems circularized

Natal Kick Velocities

- We want a large pathway, which requires:
  - Wide initial orbits
  - Low natal kicks
- 30-100 day orbital period pre-SN agrees with stable MT not CEs

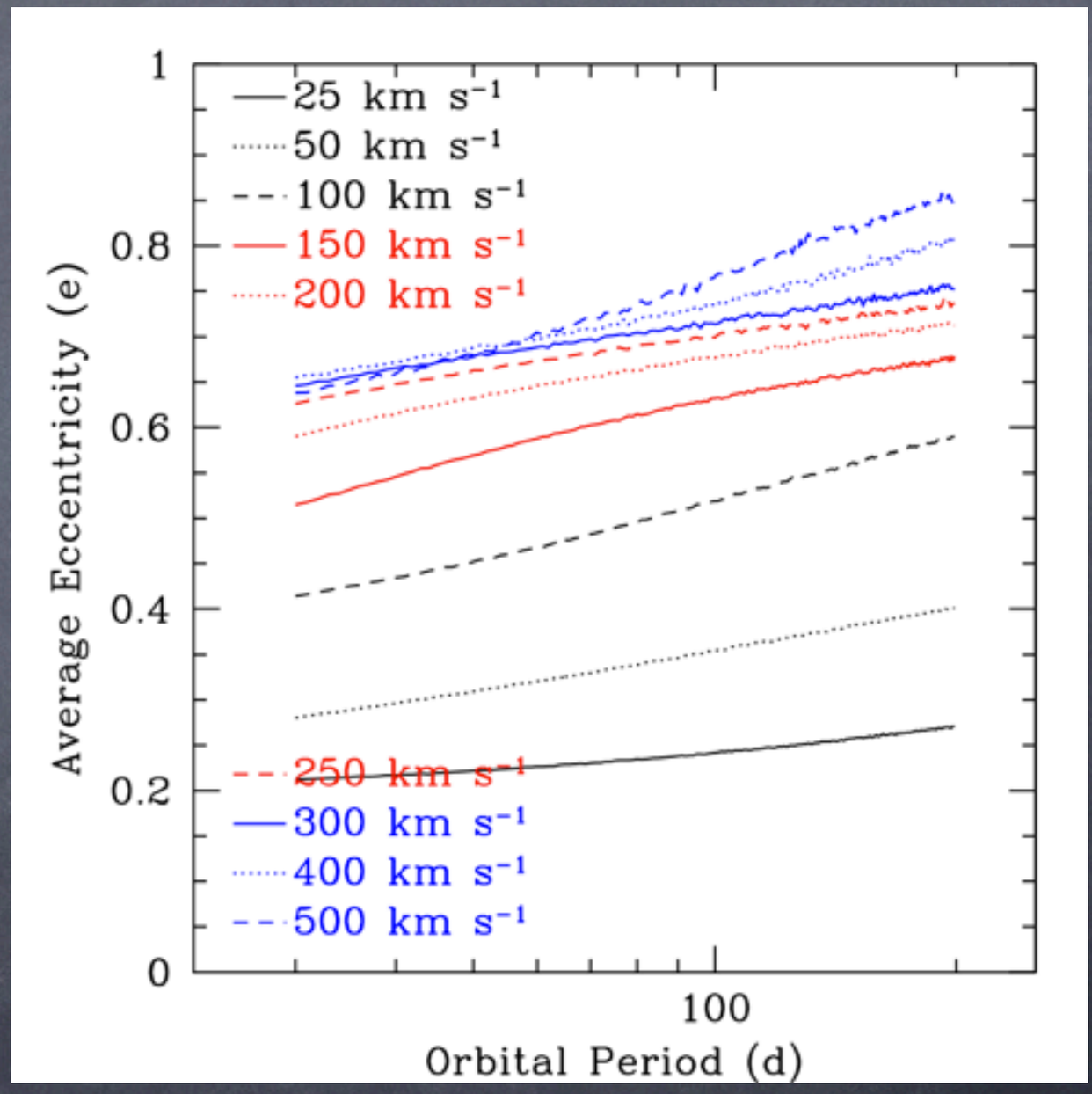


see also: Pfahl et al. 2002, Podsiadlowski et al. 2004

Natal kicks and eccentricities

- Eccentricities are (as expected) enhanced for higher natal kick velocities

- Positive correlation between orbital period and eccentricity observed for all kick velocities



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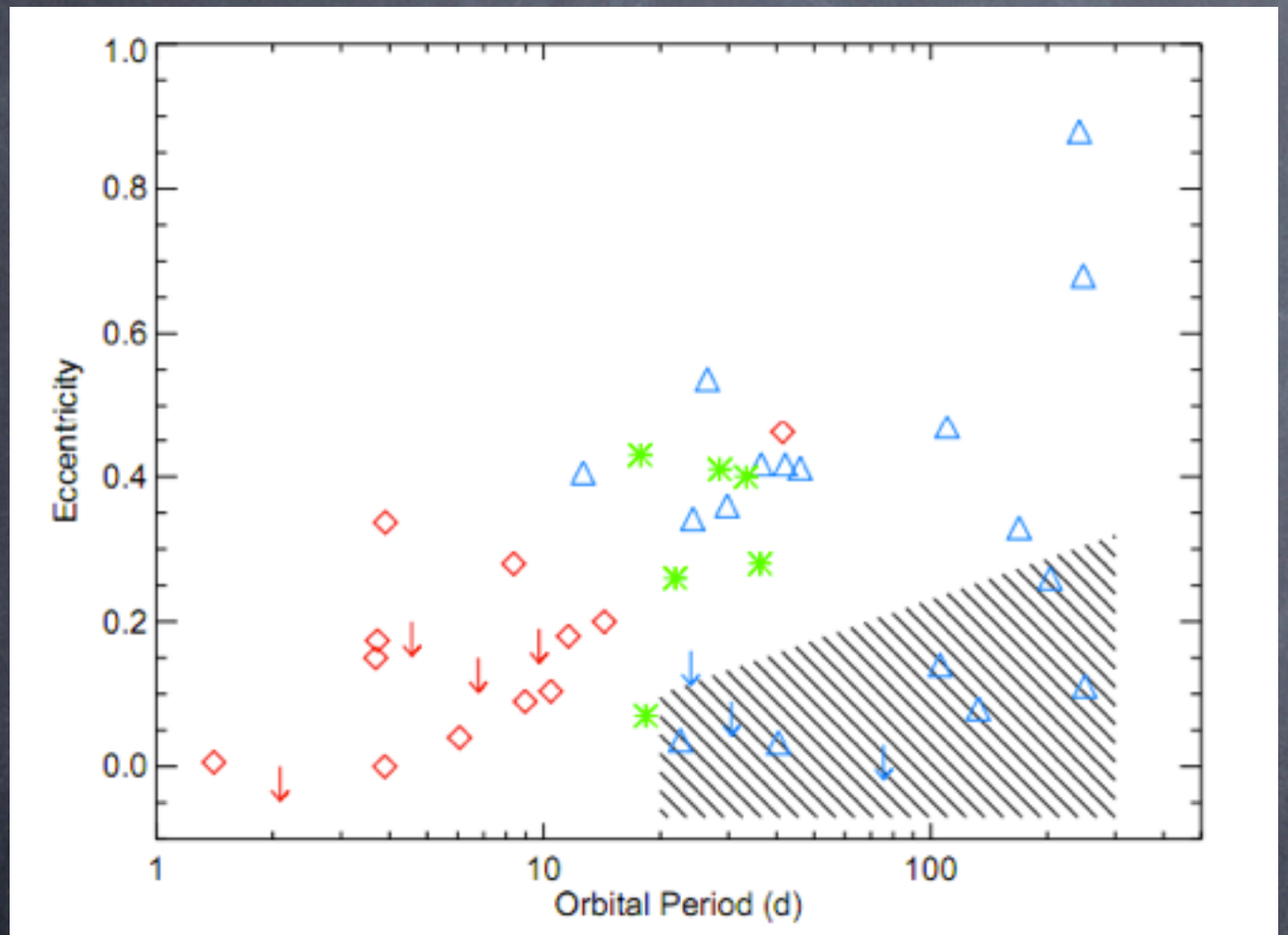
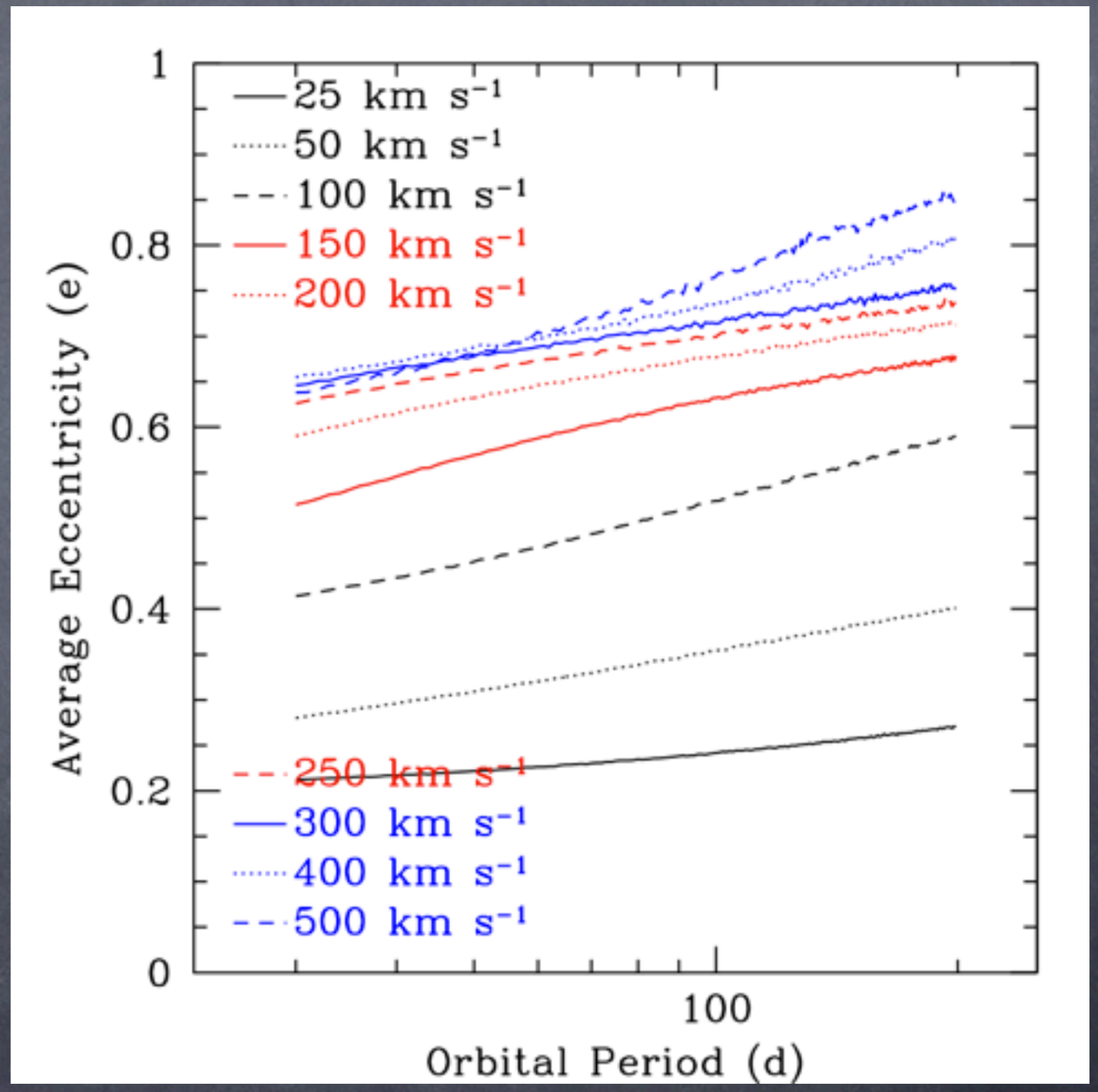


Townsend et al. 2011



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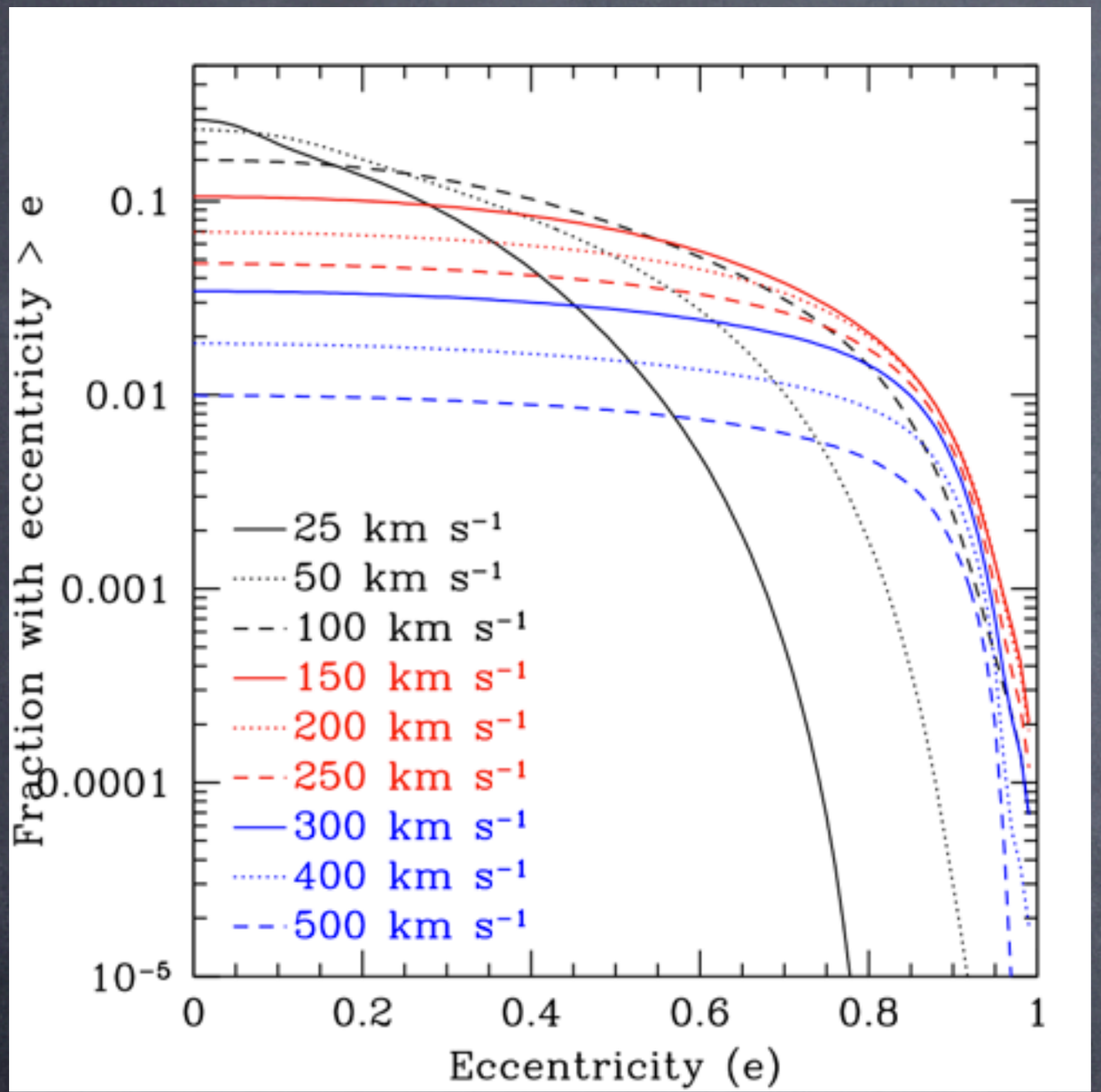
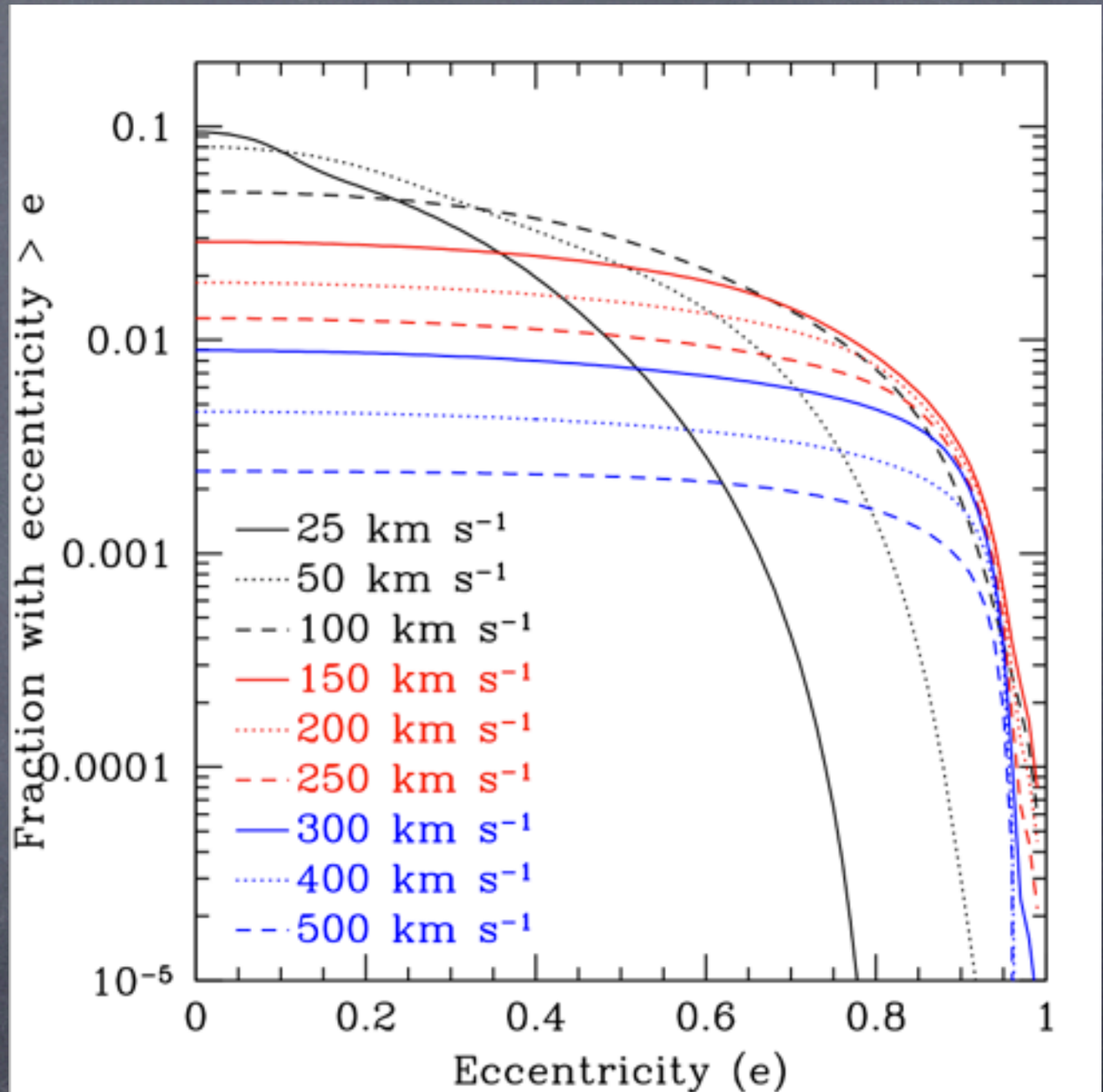
Eccentricities of BeXRB



- P > 30 d



- P > 100 d

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Advantages of this Pathway

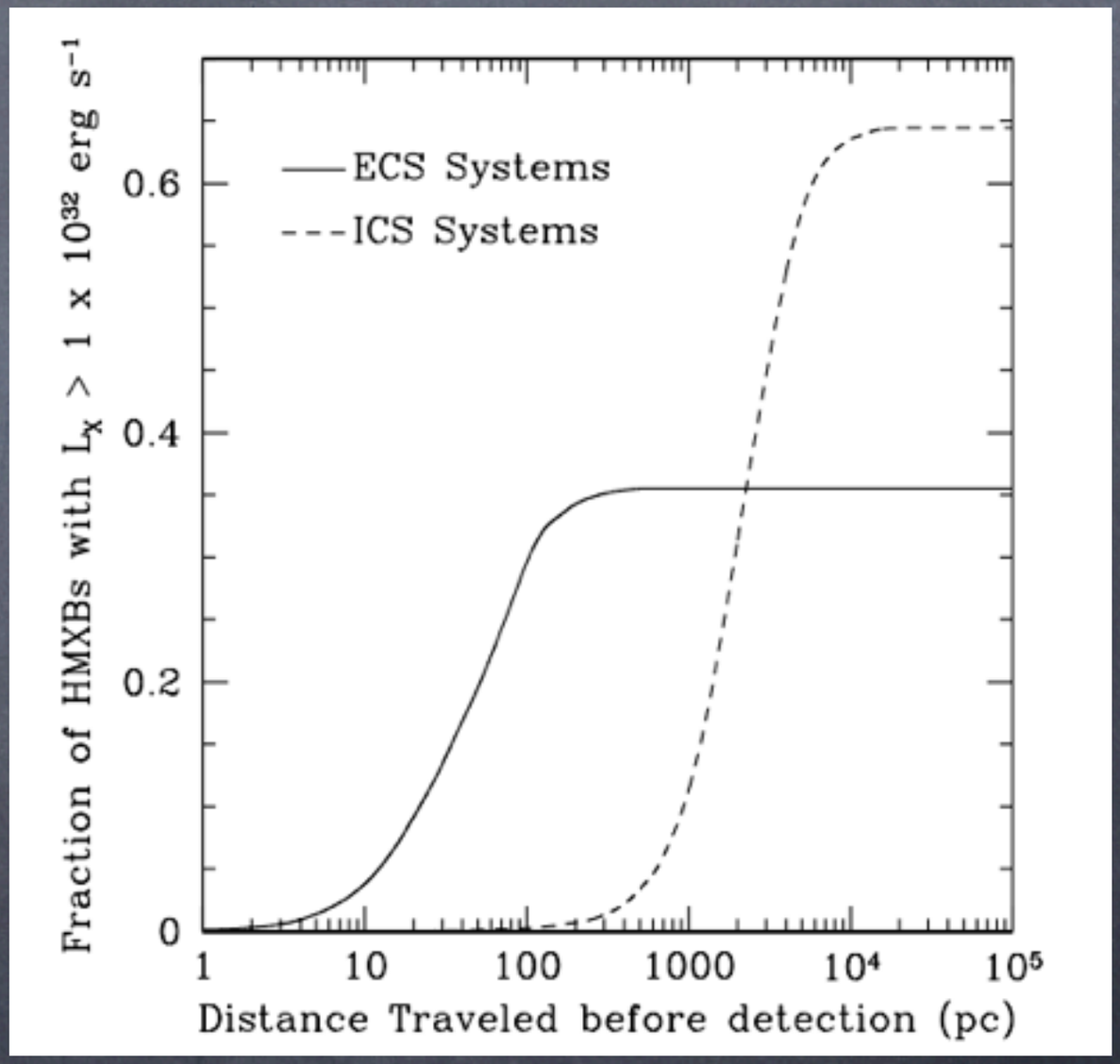
- The initial parameter space moving through the MT pathway is likely to be large:
  - Salpeter mass scale => ECS ~50% of total SN
  - Initial secondary distribution may favor "twins"
  - Wide range of initial orbital separations
  - Suppressed NS kick is very survivable

Advantages of this Pathway

- Note: Observed orbital periods and eccentricities may be highly biased compared to the dynamical population:
  - Lowest Orbital Periods
  - Highest Eccentricities
- Any correction for these effects would be likely to require even smaller SN natal kicks

Testable Predictions

- Systems born through ECS (or other low kick mechanisms) should be found closer to star formation regions than standard ICS systems



Possibly Testable Predictions

- Different SN mechanisms may induce observably different NS parameters (e.g. pulsar periods, magnetic fields) <== See previous talk by Malcolm Coe

- Provides an explanation for the lack of observed BeXRBs with black hole accretors

- Mass ratio near unity provides explanation for lack of late B type (B4-B9) donors

Conclusions

- The observed orbital characteristics of the BeXRB population strongly indicate the systems are produced via substantially diminished natal kick velocities

- The Electron Capture process naturally facilitates these dynamics and explains:
  - The mass range of observed Be donors (10-15 Msun)
  - The spinup of Be stars
  - The large population of systems compared to SGXRB

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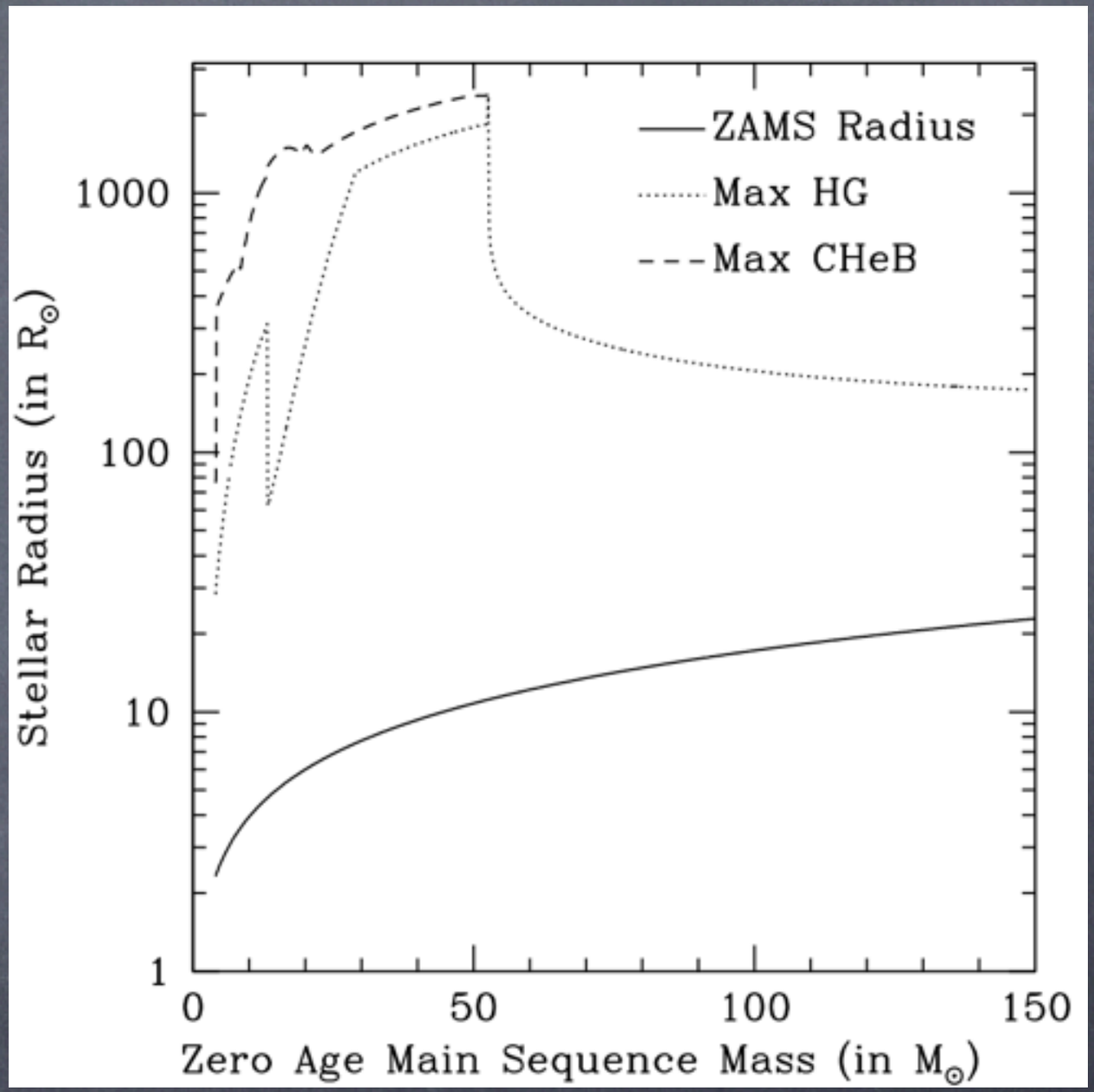
BUT!!!

Future Work

- Some difficulties in a current model of BeXRB:
  - SSE code contains odd behavior at 13 Msun - right in the middle of the ECS range
- Be wind model still not developed (should be trivial, right?)



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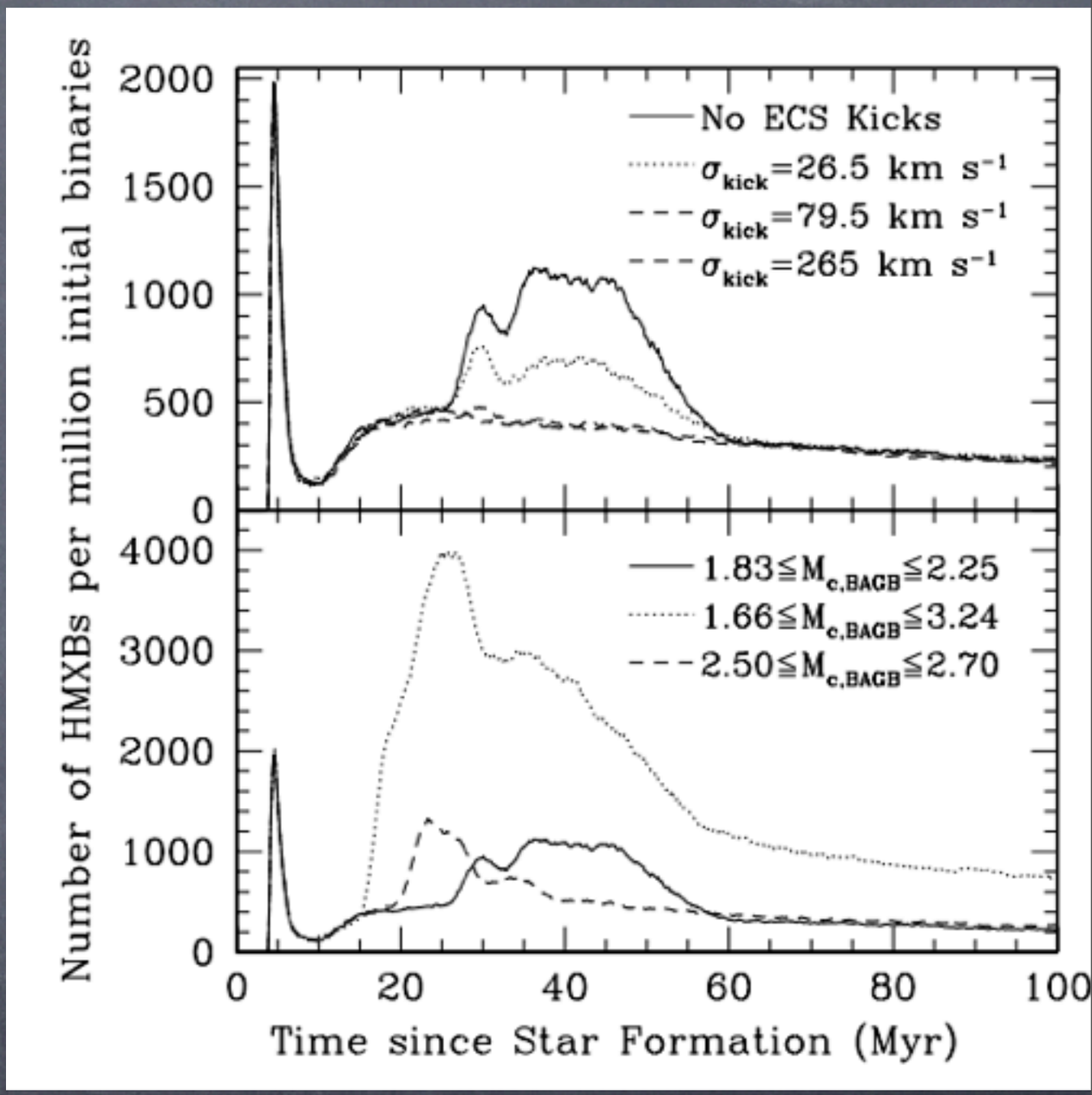

Future Work

- We (Tassos Fragos (CfA), Kalogera (Northwestern)) are currently in development of a code which links live stellar evolution to the previously developed MESA code (Paxton, KITP)

Stay Tuned!