PSR J0737-3039: An Extraordinary Double Neutron Star System

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Overview

- Pulsars and millisecond pulsars
- Formation of double neutron star binaries
- Properties of PSR J0737-3039
- Constraints on pre-SN binary parameters
- Most probable isotropic kick velocity
- (Preliminary) Summary
- Recent results/work in progress

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Pulsars and millisecond pulsars

Rapidly rotating neutron stars whose magnetic field axis is inclined with respect to their spin axis

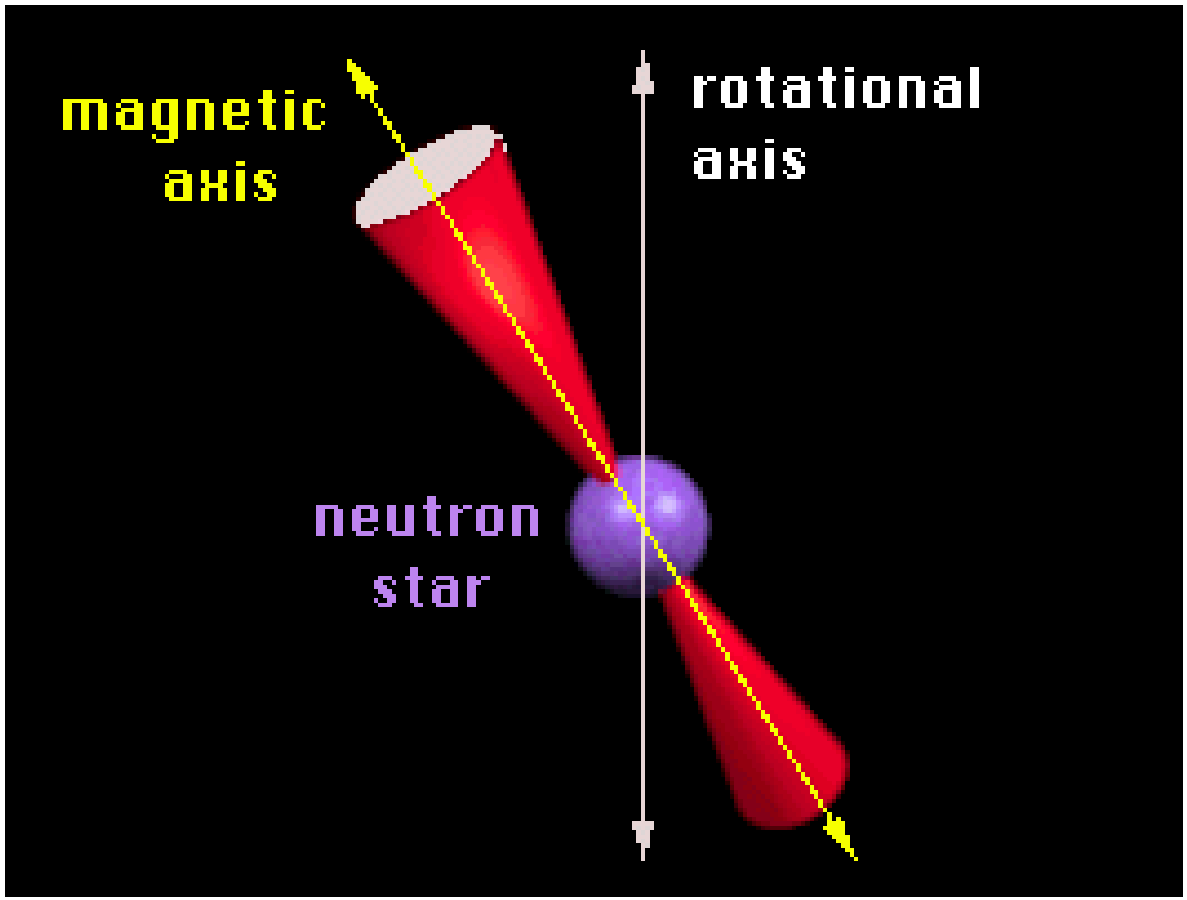

Figure credit: http://science.nasa.gov/newhome/help/tutorials/pulsar.htm

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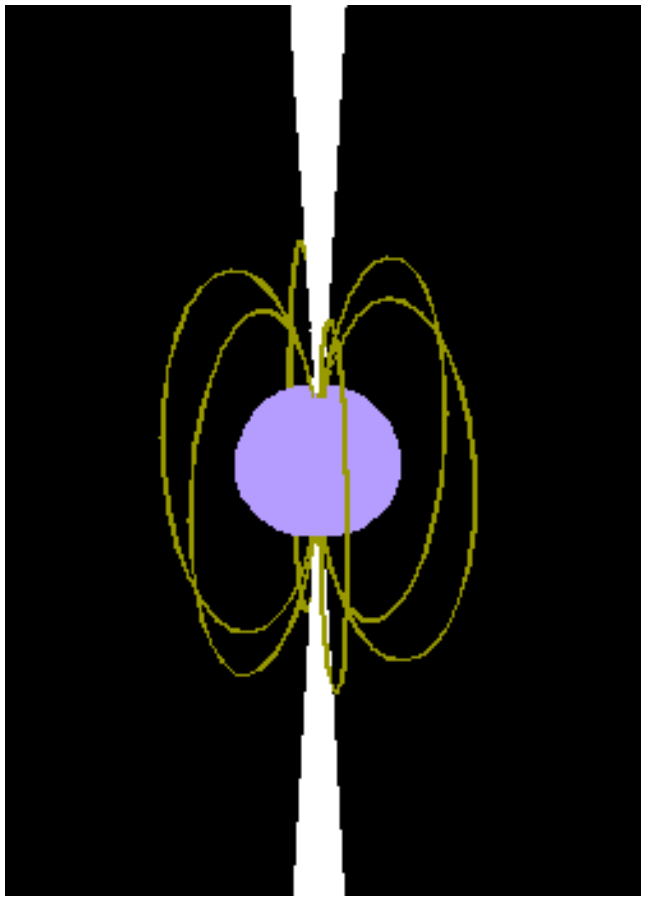

Figure credit: http://www.amherst.edu/~gsgreenstein/progs/animations/pulsar_beacon/

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Formation of DNS binaries

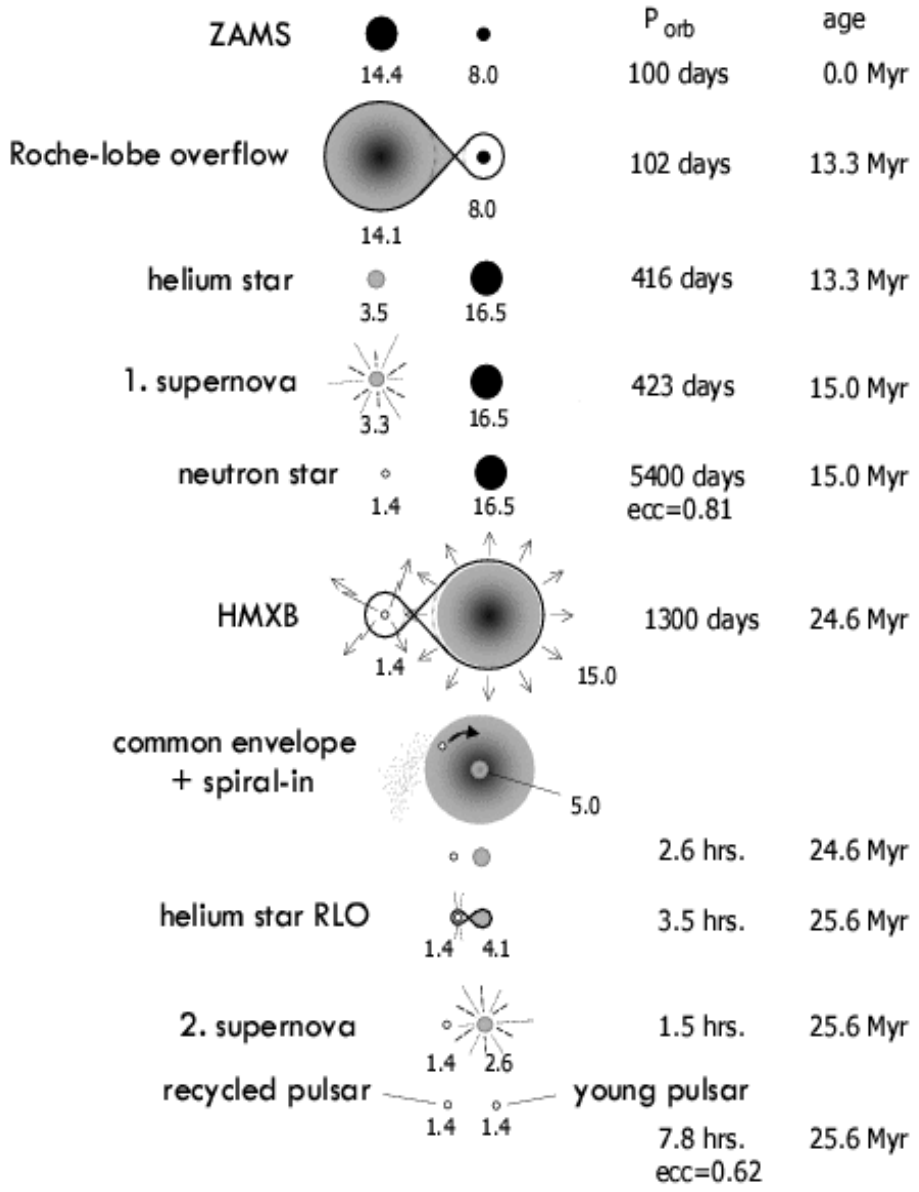
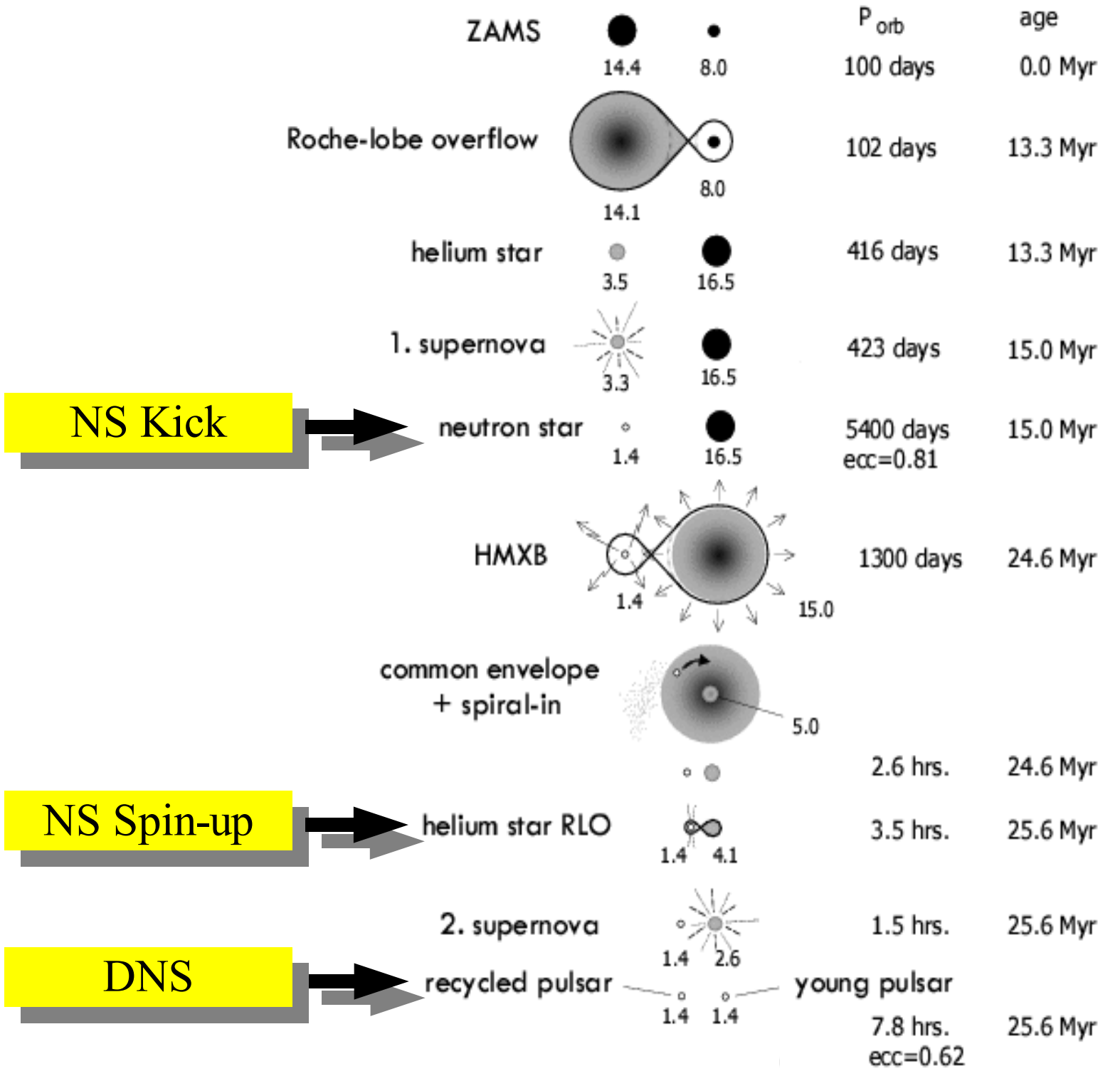


Figure credit: Tauris & van den Heuvel (2003)



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PSR J0737-3039 Properties I

- First known DOUBLE PULSAR system
  - Pulsar A: 23ms (fastest known spin for a DNS pulsar)
  - Pulsar B: 2.8s
  - Orbital period: 2.4 hrs (closest known DNS orbit)
  - Eccentricity: 0.09 (least eccentric of all known DNS)
  - Periastron advance: 16.9° per yr (fastest of all known DNS)

PSR J0737-3039 Properties II

- Coalescence time: 85Myr (shortest of all known DNS)
  - ✗ drastic increase in estimates for gravitational wave detections by ground-based interferometers (Kalogera et al. 2004)
- Edge-on orbit ⇒ eclipses! (unique probe into pulsar winds and magnetospheres)
- Remarkable progenitor constraints (wait and see!)

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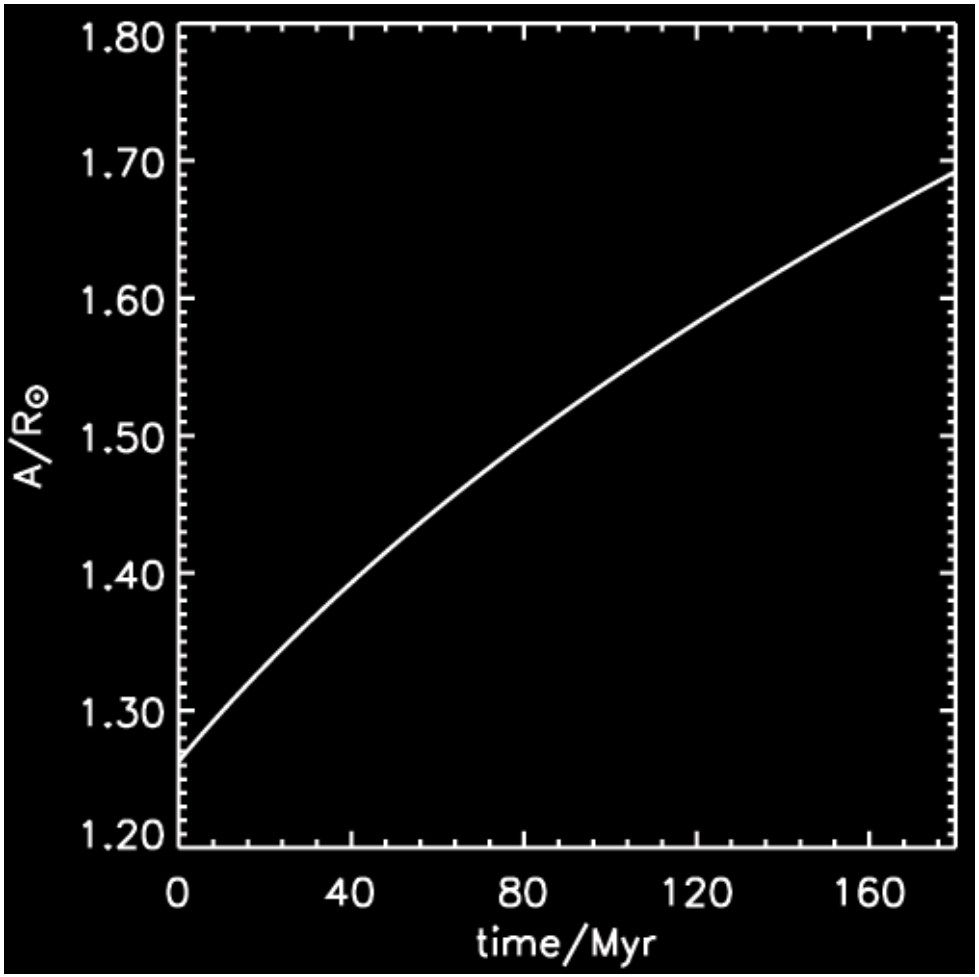
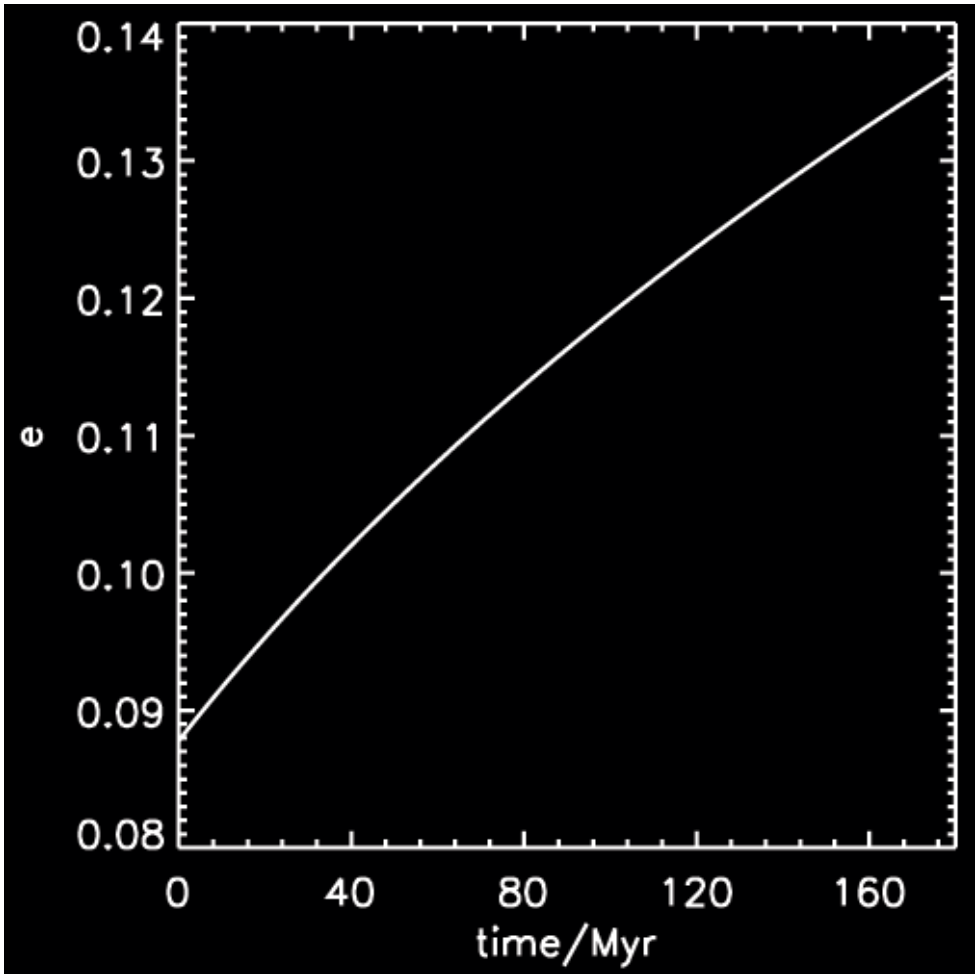
Post-SN Orbital Parameters

Integrate dA/dt and de/dt due to gravitational radiation backwards in time:





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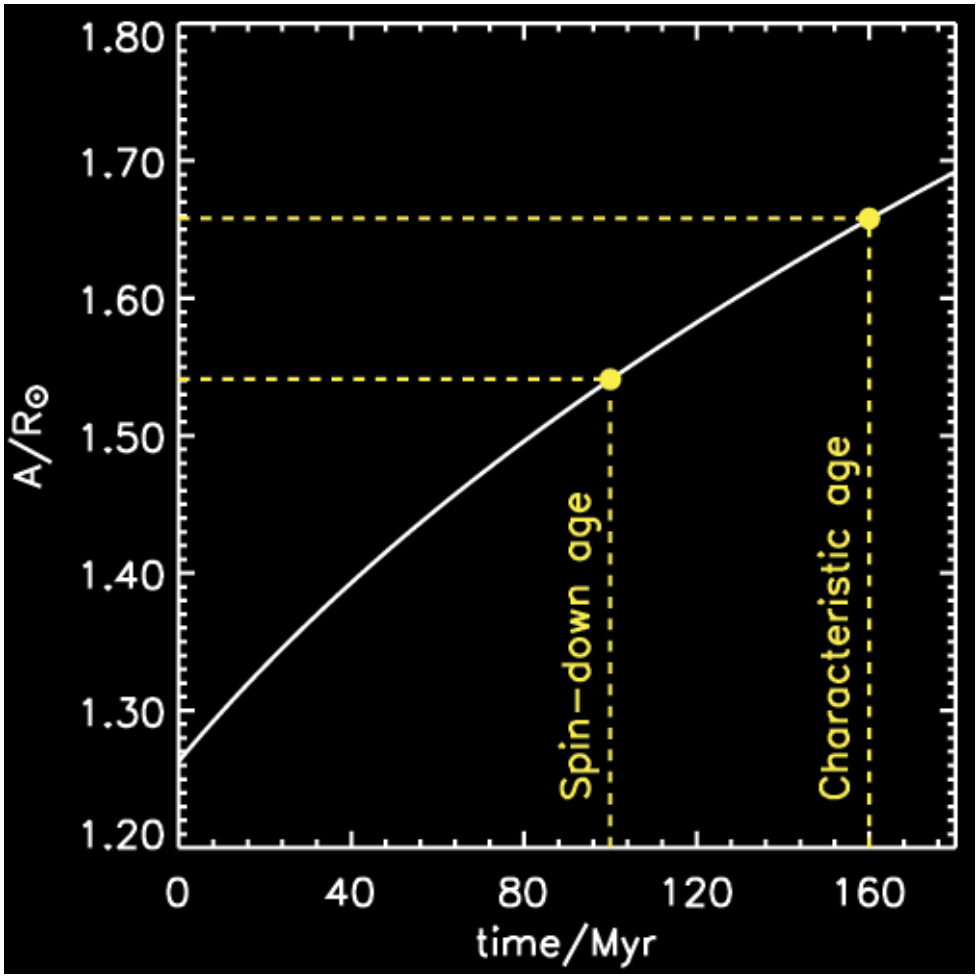

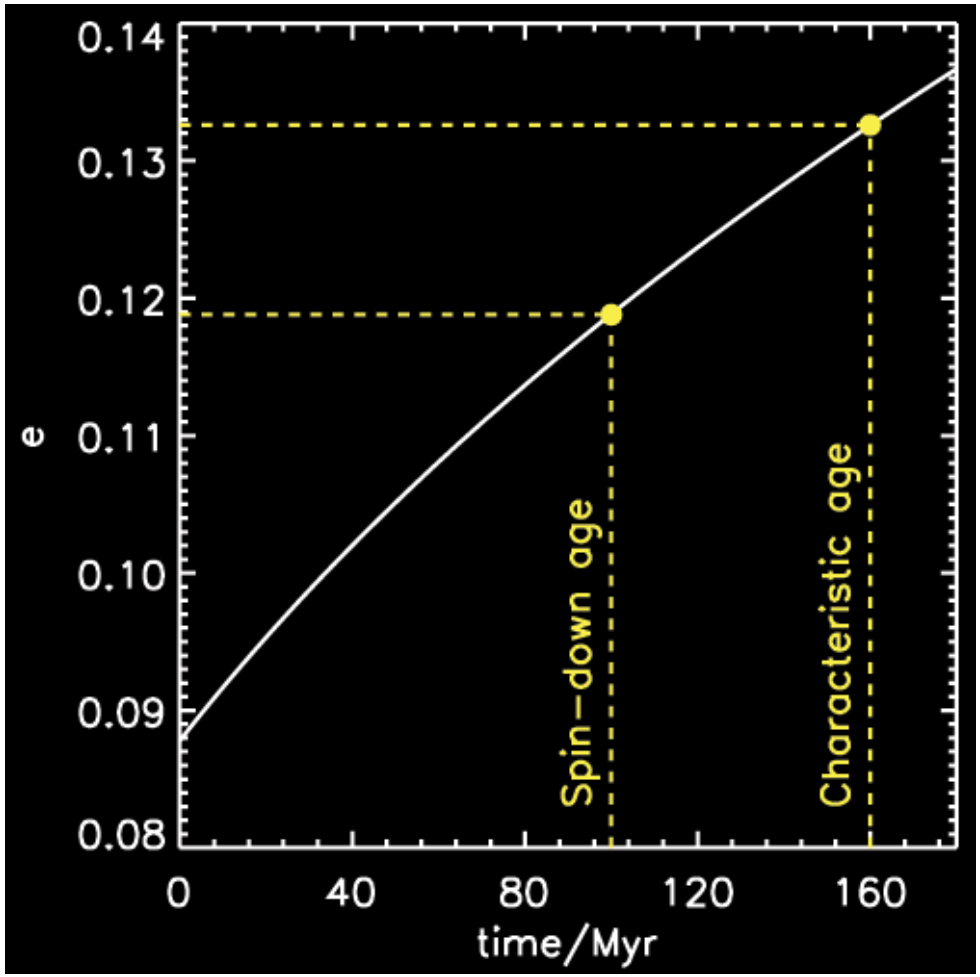

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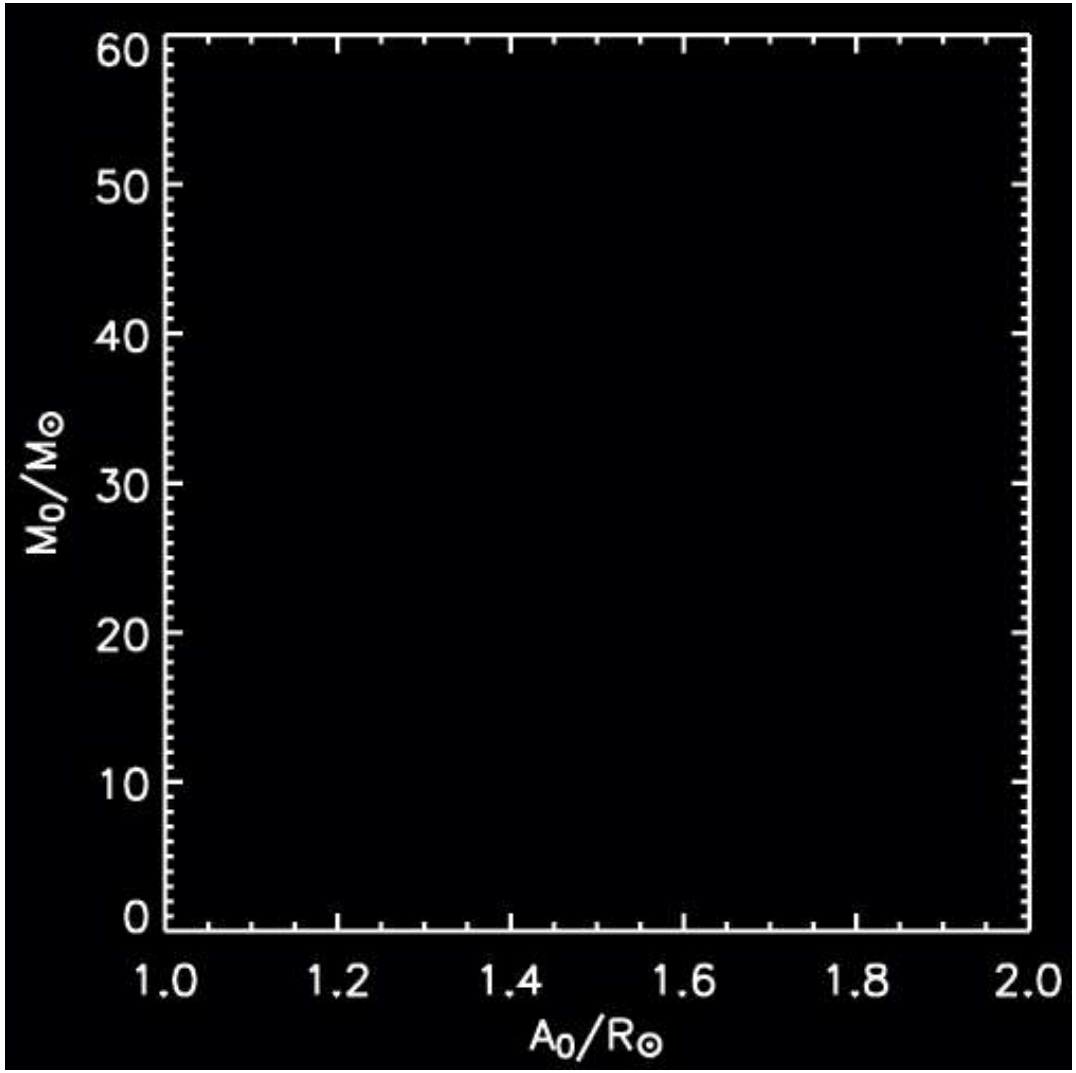
Constraints on Pre-SN Binary Parameters



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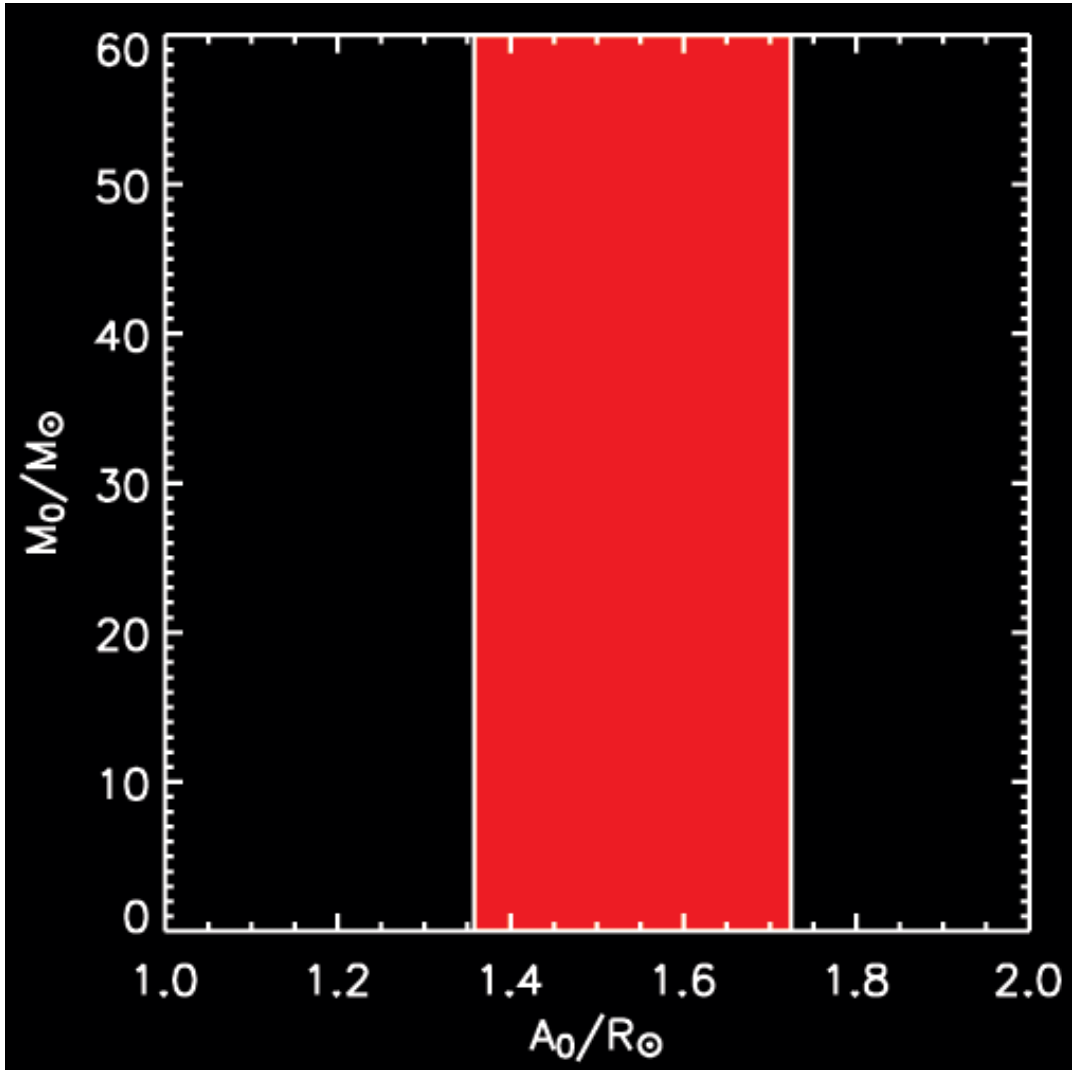

(1) Post-SN orbit must contain the pre-SN position of both stars:
$A\,(1-e) < A_0 < A\,(1+e)$
(Flannery & van den Heuvel 1975)

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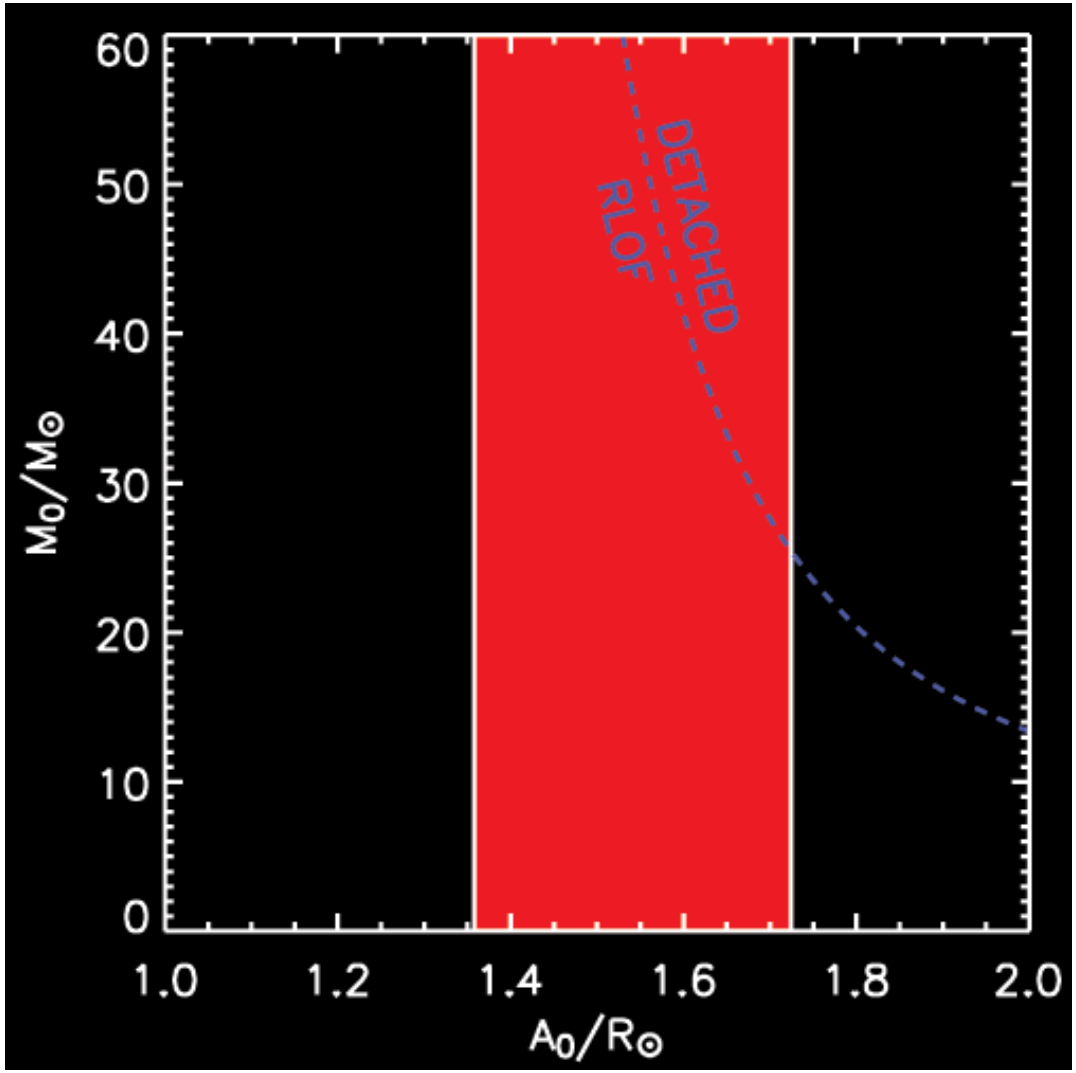

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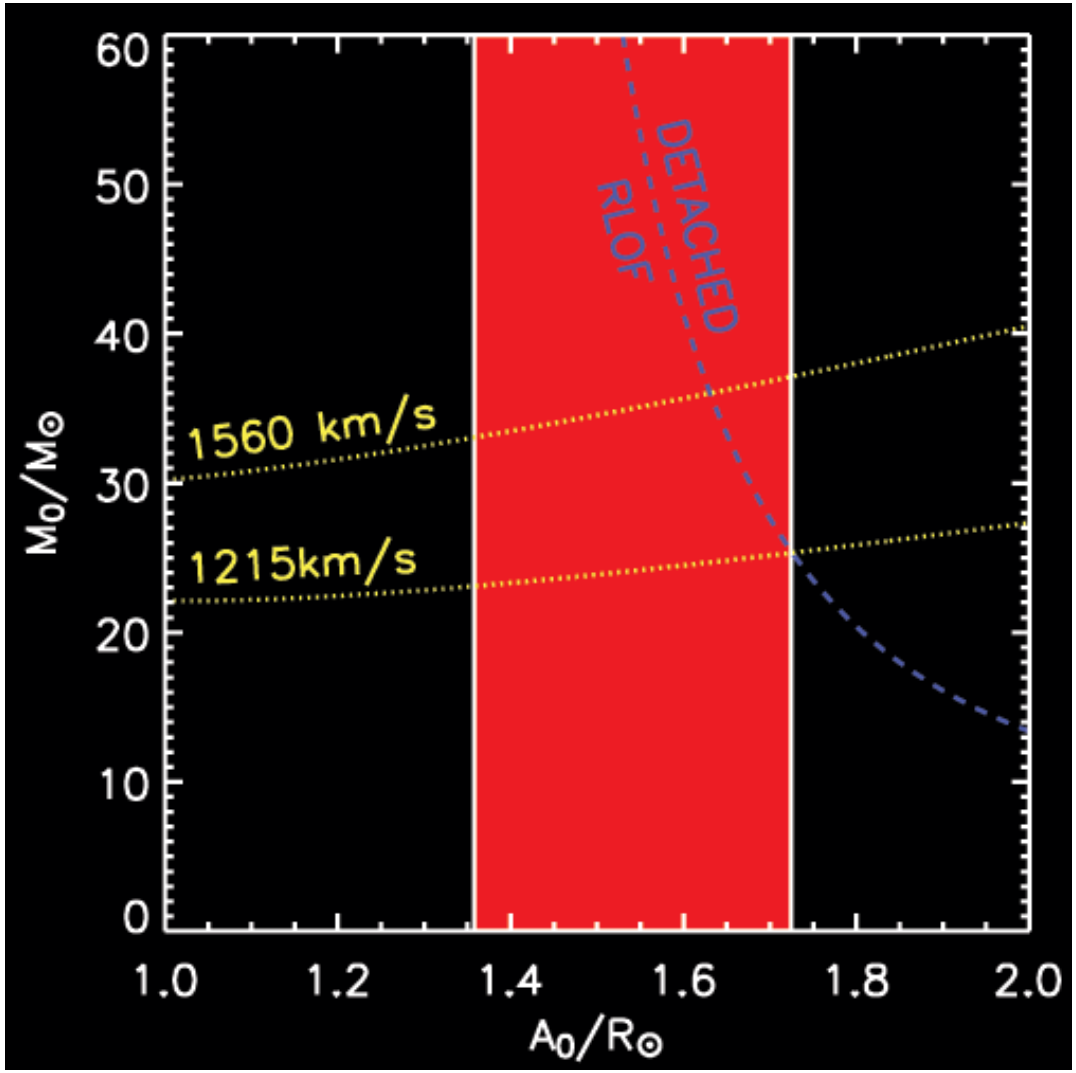

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(3) Real kick direction:
$M_0 \leq M_{0,max} = f(V_k)$
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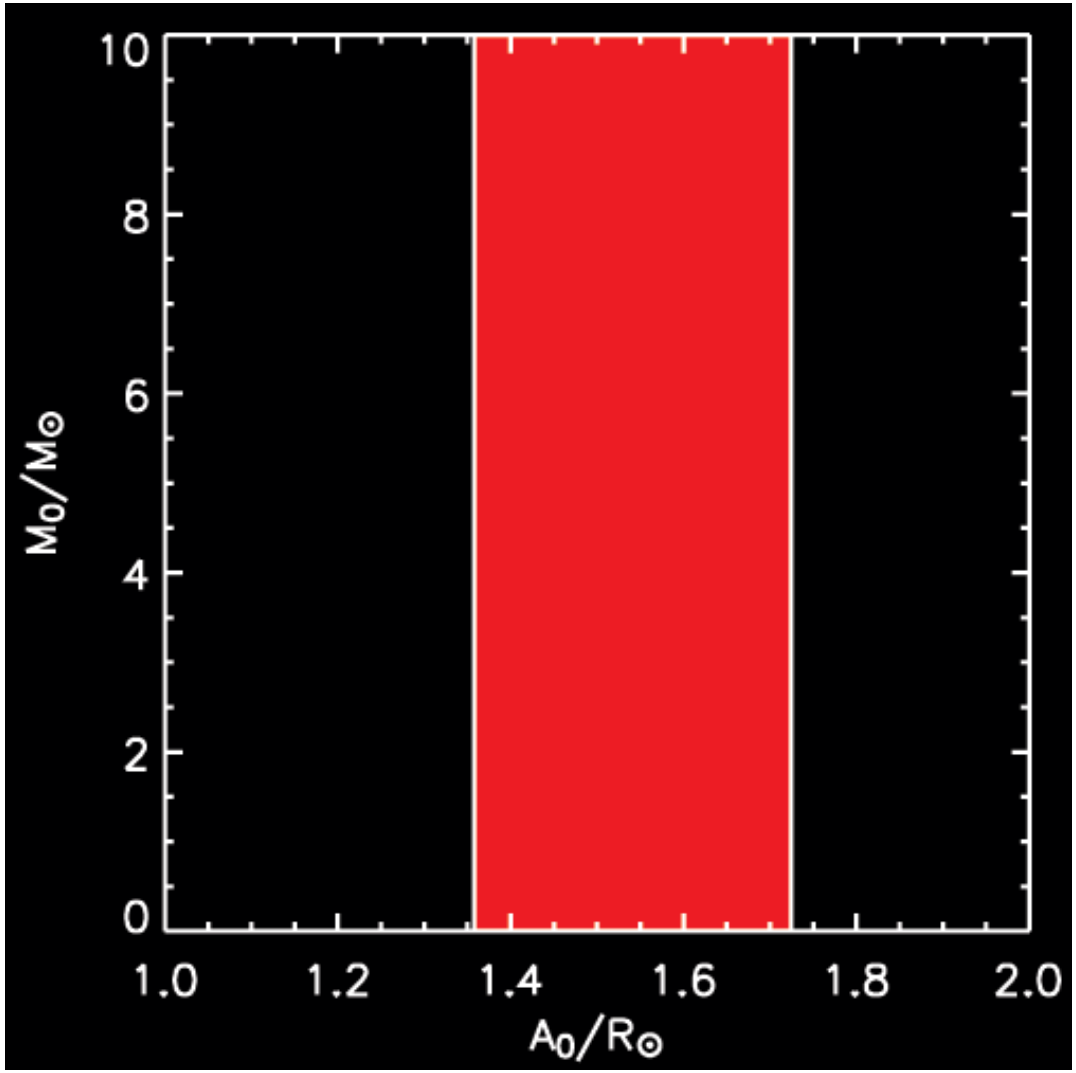

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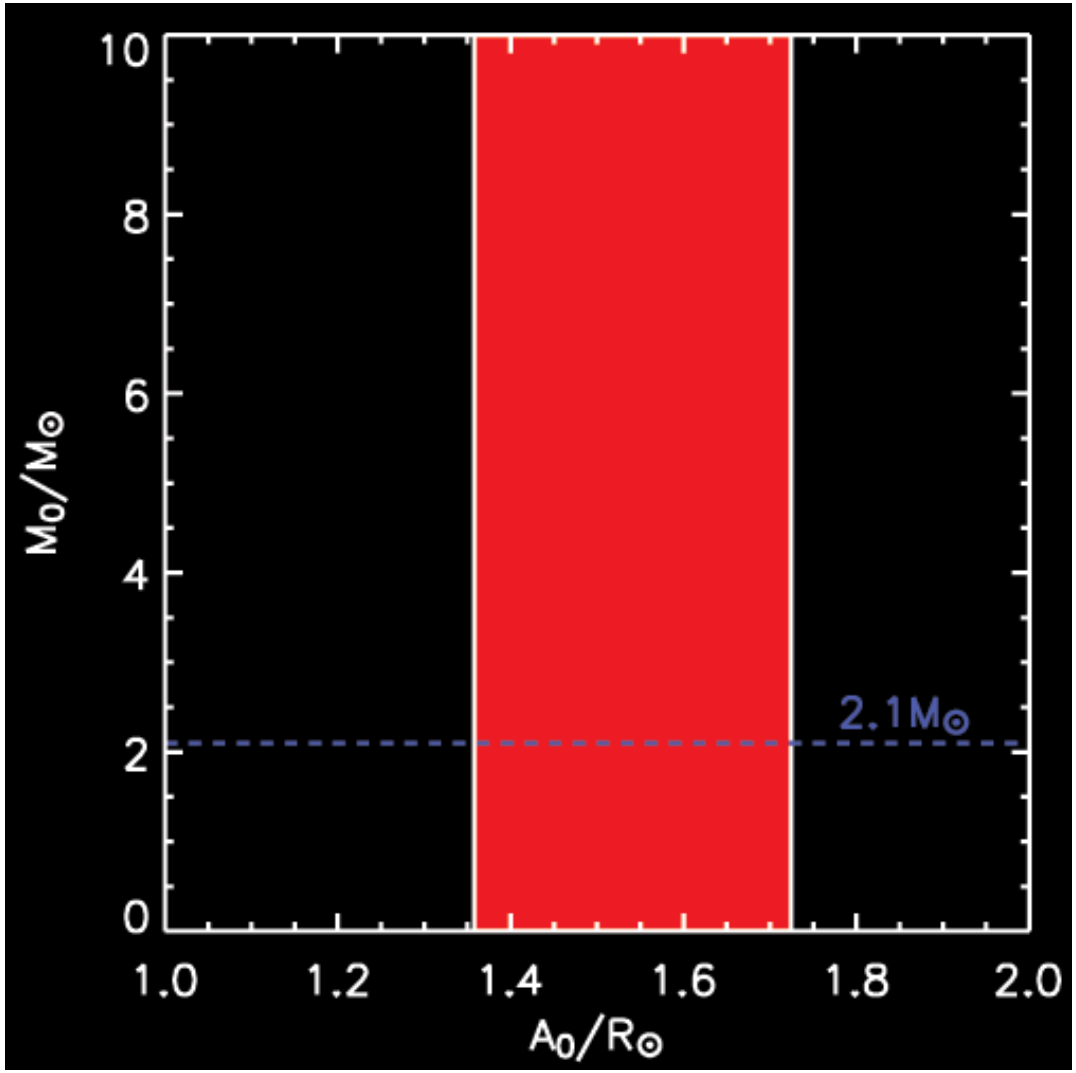

(1) $A(1-e) < A_0 < A(1+e)$

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$M_0 > 2.1 M_\odot$

(Habets 1986)

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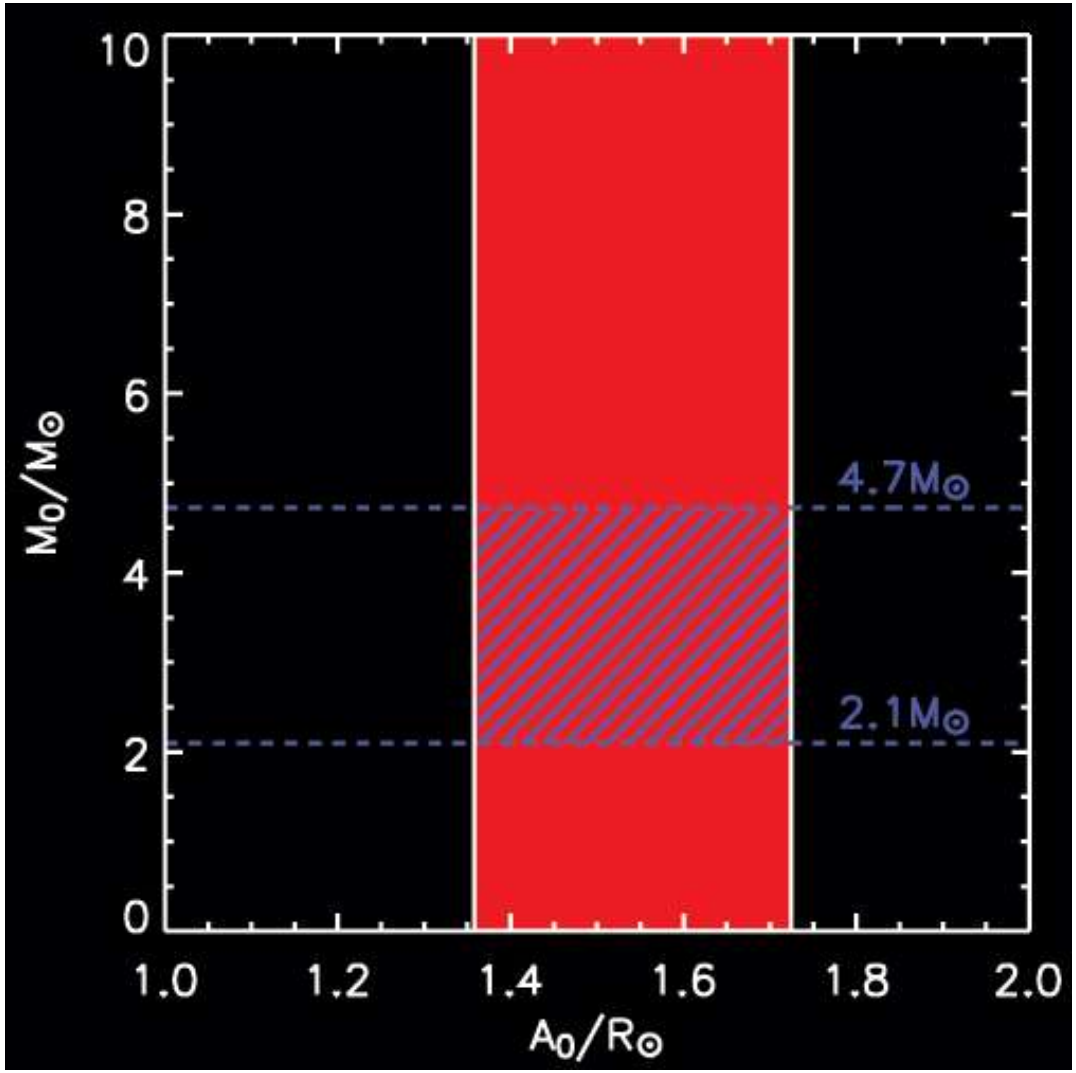

(1) Circular pre-SN orbit

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(4) To avoid a merger:
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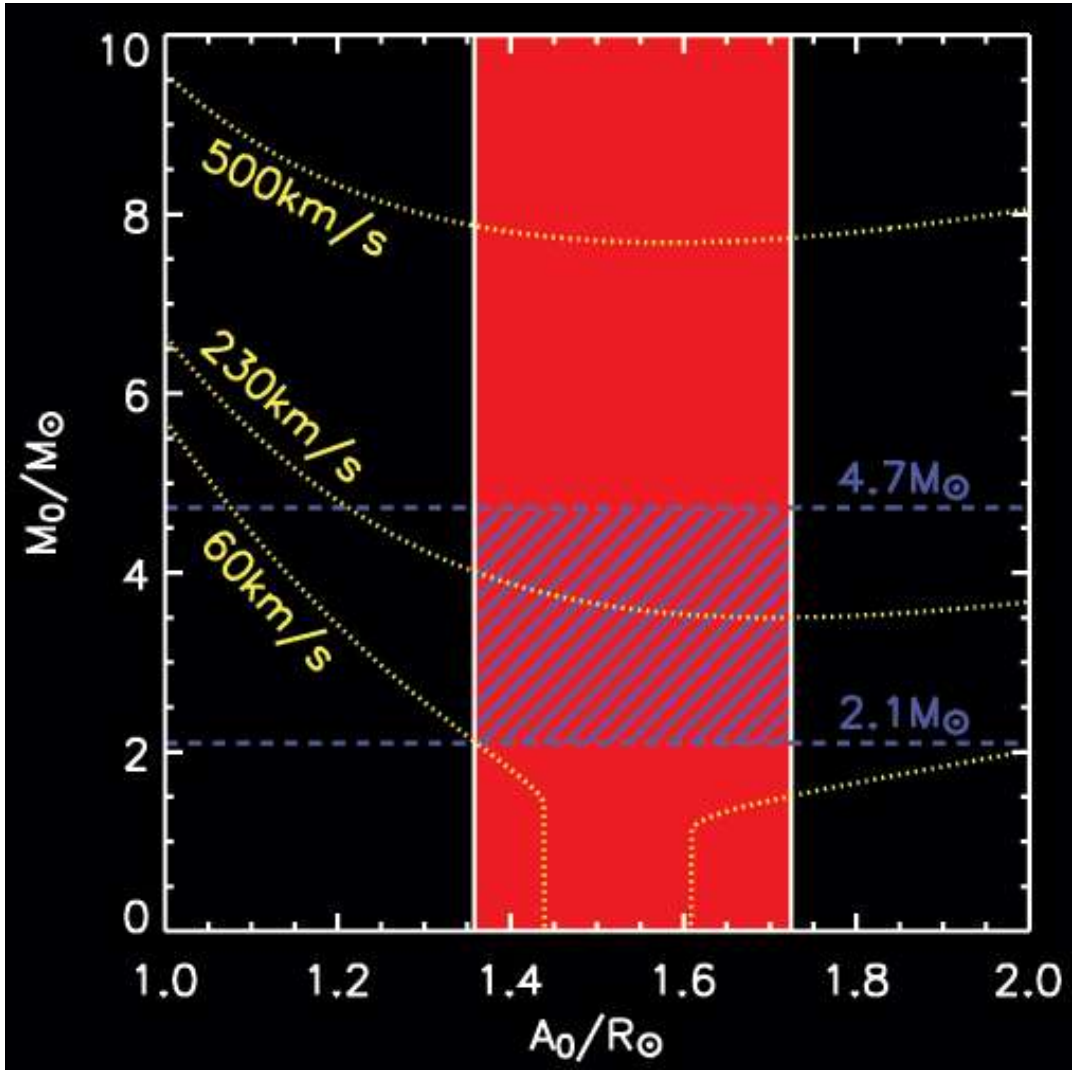

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(5) $M_0 \leq M_{0,max} = f(V_k)$
$60km/s \leq V_k \leq 1560km/s$

The Most Probable Isotropic Kick Velocity

$$2.1M_{\odot} \leq M_0 \leq 4.7M_{\odot}$$

$$1.36R_{\odot} \leq A_0 \leq 1.72R_{\odot}$$

V_k

$$\theta_1 \leq \theta \leq \theta_2$$

$$\phi_1 \leq \phi \leq \phi_2$$

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V_k

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$\phi_1 \leq \phi \leq \phi_2$

Isotropic kicks:

$$P(\theta, \phi) = \frac{\sin\theta}{4\pi}$$

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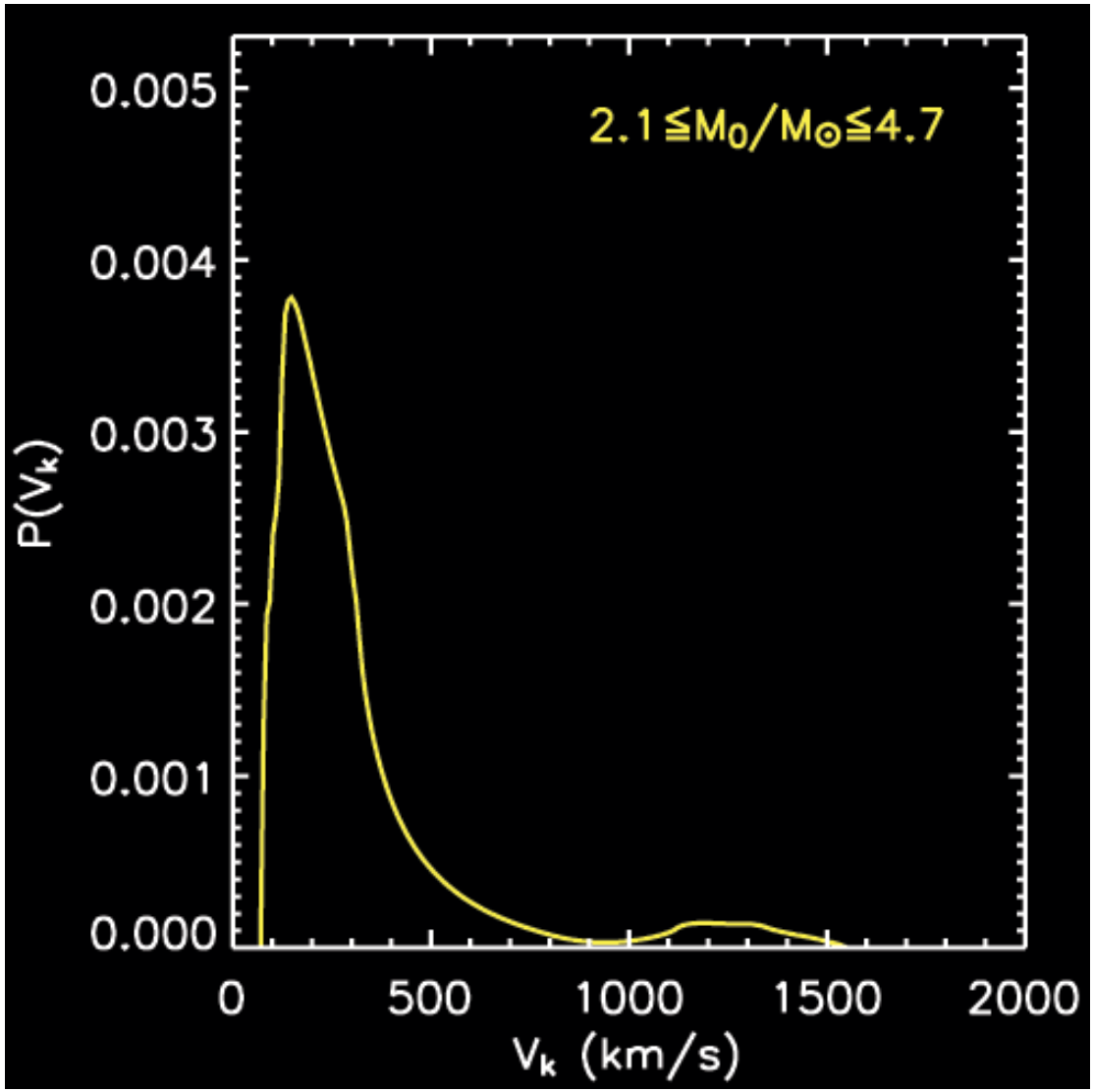

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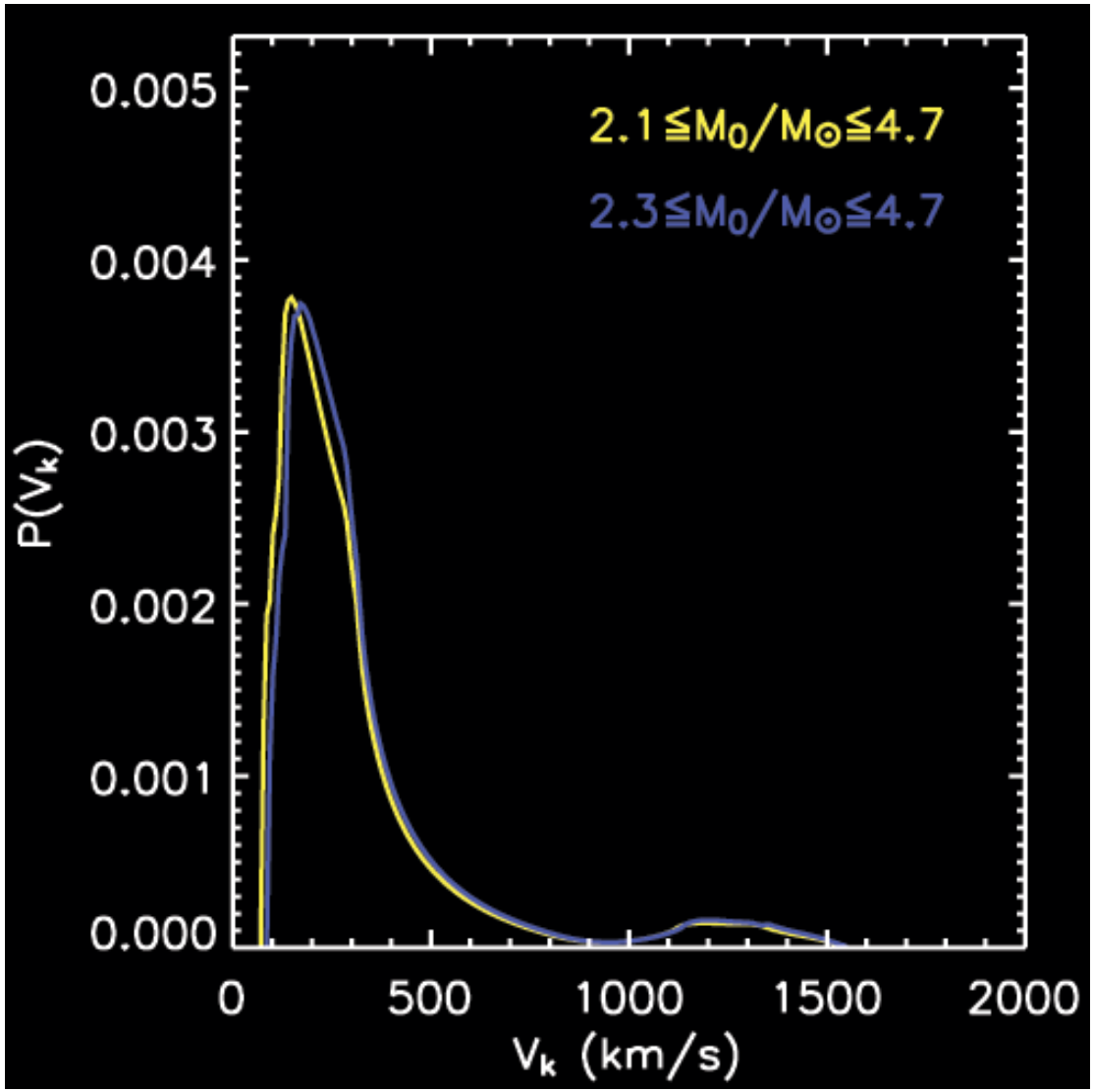

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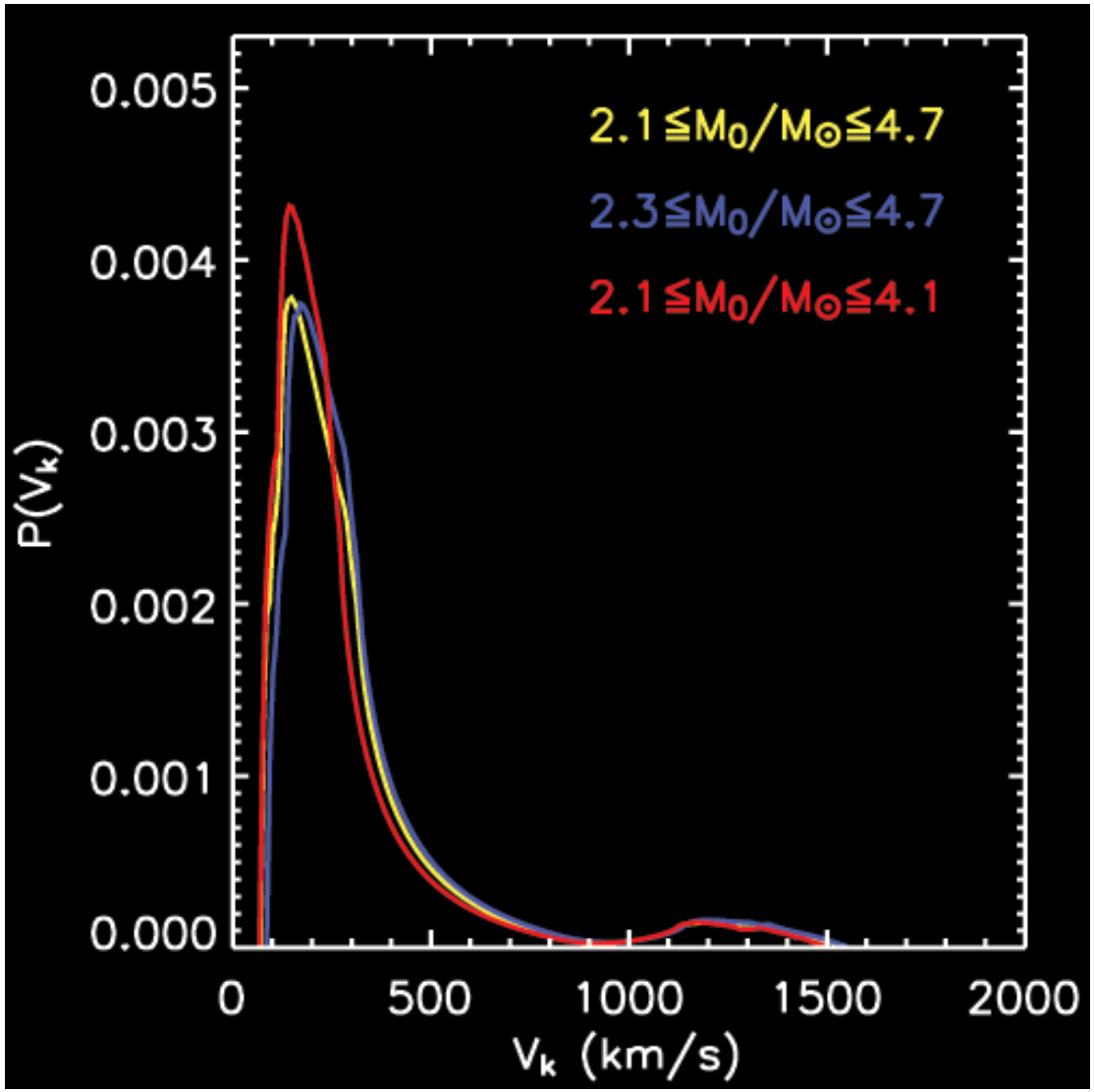

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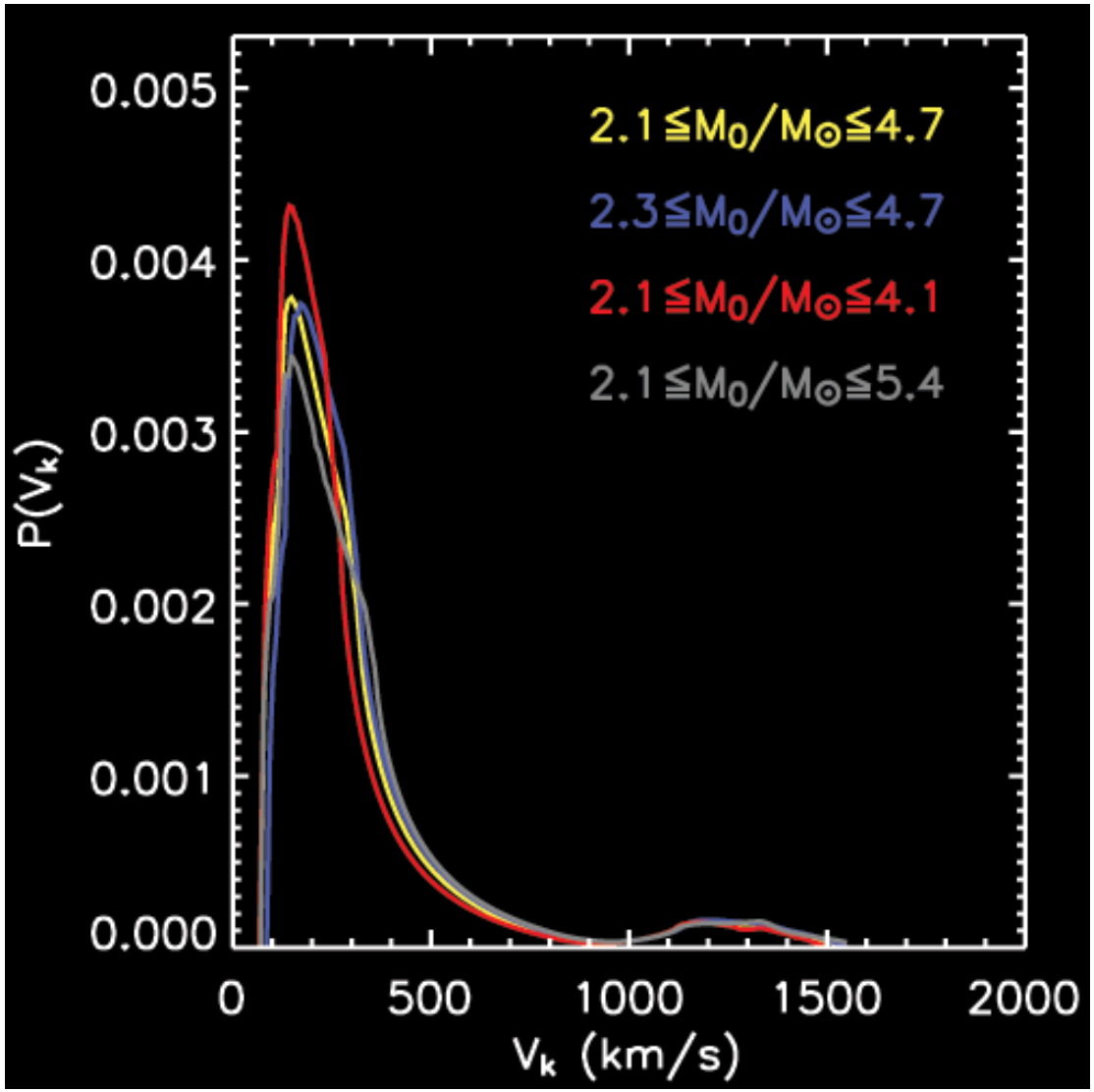

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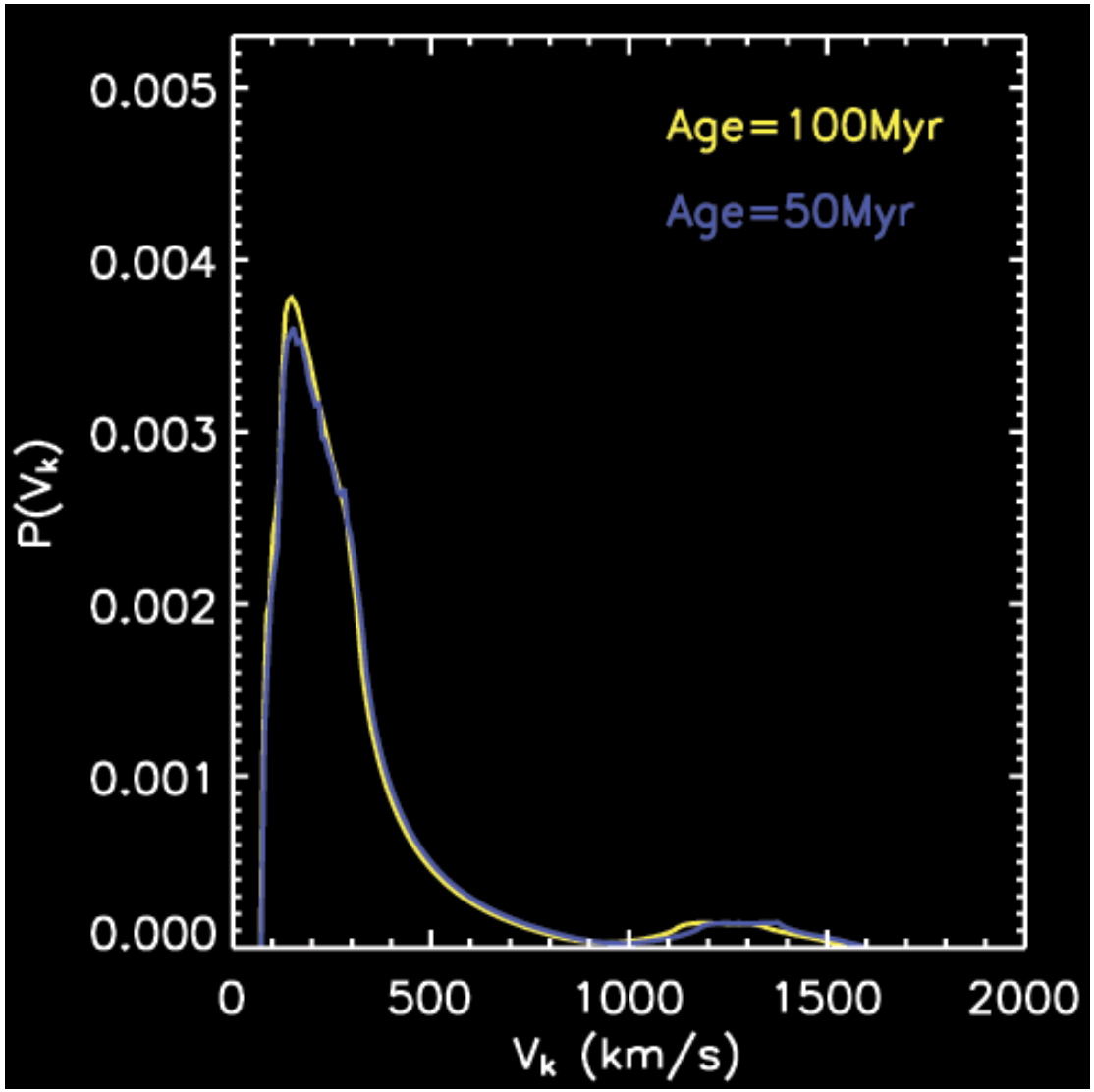

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(Preliminary) Summary

Progenitor constraints

- ✗ Pulsar B's helium star progenitor: $2.1M_{\odot} \leq M_0 \leq 4.7M_{\odot}$
- ✗ Pre-SN orbital separation: $1.36R_{\odot} \leq A_0 \leq 1.72R_{\odot}$
- ✗ Helium star is most likely transferring mass to the first-born NS at the time of the second SN explosion

Pulsar B kick velocity constraints

- ✗ Allowed range: 60 km/s $\leq V_{kick} \leq$ 1560 km/s
- ✗ Most probable isotropic kick velocity: $\simeq$150km/s

See also Willems & Kalogera (2004, ApJ 603, L101)

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Recent Results/Work in Progress

- Additional constraints from velocity measurements
  - ✗ Knowledge of post-SN systemic velocity imposes additional constraints on progenitor and formation of PSR J0737-3039
  - ✗ But... post-SN systemic velocity ≠ current systemic velocity
    - ➔ Galactic motion must be traced back to the time of the system's formation
    - ➔ Requires knowledge of 3D velocity

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Recent Results/Work in Progress

- Additional constraints from velocity measurements
  - ✗ Ransom et al. (2004): 2 velocity components in the plane perpendicular to the line-of-sight, but... orientation of the velocity vector is unknown
  - ✗ Third velocity component: radial velocity is also unknown

- Galactic motion depends on 2 unknown parameters

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Recent Results/Work in Progress

- Despite the 2 unknown parameters
  - ✗ Much tighter constraints on progenitor, kick velocity, and age(!) for many parameter combinations
  - ✗ Kick-velocity distribution only shows 1 peak, but the most probable value can range from $\simeq$100km/s to more than $\simeq$1500km/s
  - ✗ Prediction for pulsar A spin-orbit misalignment

The End

For the full story:

Astrophysics Theory Group Meeting:

13 May 2003, 11am, Dearborn 23

OR

Keep an eye on astro-ph for

"Pulsar kicks and spin tilts in the close double neutron stars PSR J0737-3039, PSR B1534+12 and PSR 1913+16"

by Willems, Kalogera & Henninger!