Neutron Stars at Birth: Parent Masses & Parental Kicks

What do NS-NS tell us ?

(and a bit more)

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Special Thanks to:

Bart Willems

Tsing Wai Wong

NS formation

Questions for this talk:

- kick magnitude: low (<~ 100km/s) or high (~ 200-300 km/s) ?
- He progenitor mass: low (<2Mo) or higher ?
- Can we distinguish between ECS & Fe-core SN?

NS Progenitor Masses: Low (<2Mo) or High ?

- 'standard' assumption: > 2.1-2.3 Mo for Fe core collapse
  (e.g., Habets 1986)

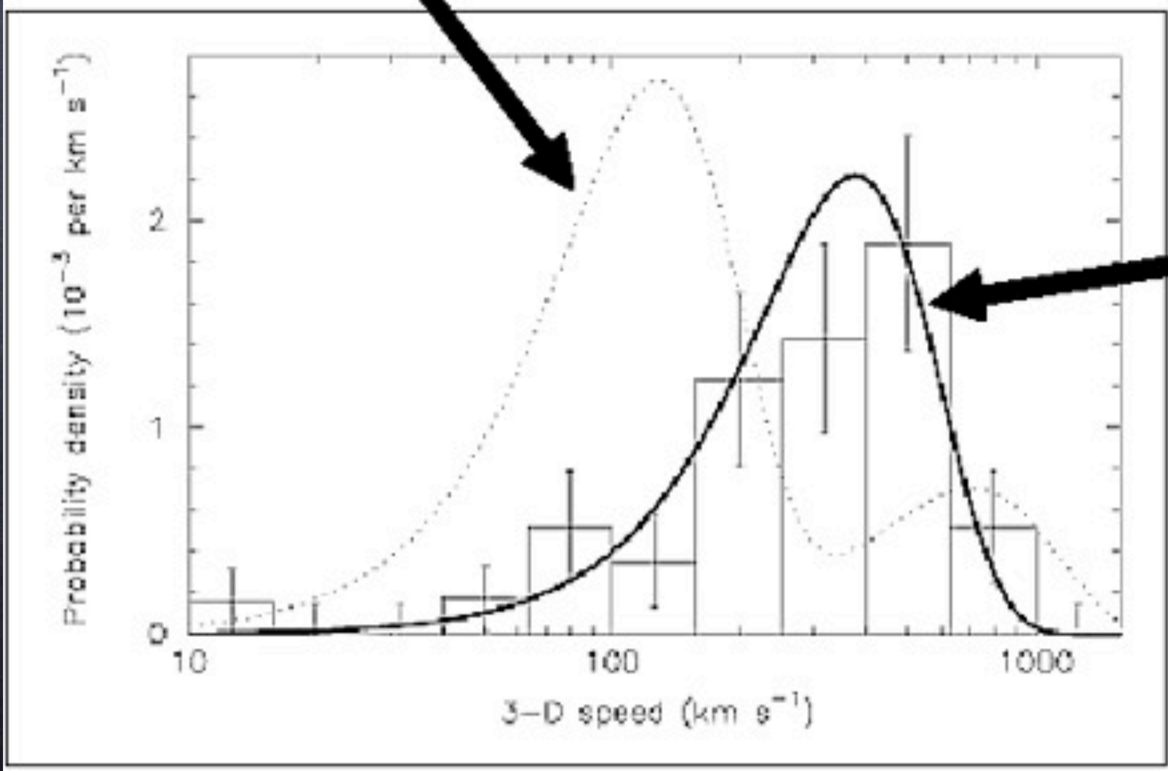
- Stable Mass Transfer from He-rich progenitor onto NS #1 allows for lower masses right before SN #2
  (Dewi et al. 2002, Ivanova et al. 2003, Dewi & Pols 2003)

- Electron-Capture SN allows for lower masses down to ?Msun (depending on details of stellar evolution models)
  (Nomoto 1984, 1987, Pols et al. 1998, Hurley et al. 2000, Podsiadlowski et al. 2004 Eldridge et al. 2006, Ivanova et al. 2007, Poelarends et al. 2007)

NS Kick Magnitudes

Radio Pulsar Proper Motions: High Kicks Favored

Arzoumanian et al. (2002):
- Bimodal Gaussian
- Dispersions: 90km/s (40%) + 500km/s (60%)



Hobbs et al. (2005):
- Single Maxwellian
- Dispersion: 265km/s
- Average: 400km/s

(also: Zou et al. 2005)

⇨ Significant neutron star kicks

NS Kick Magnitudes

Low Kicks Favored (< 20-50 km/s) ?

Beyond NS-NS

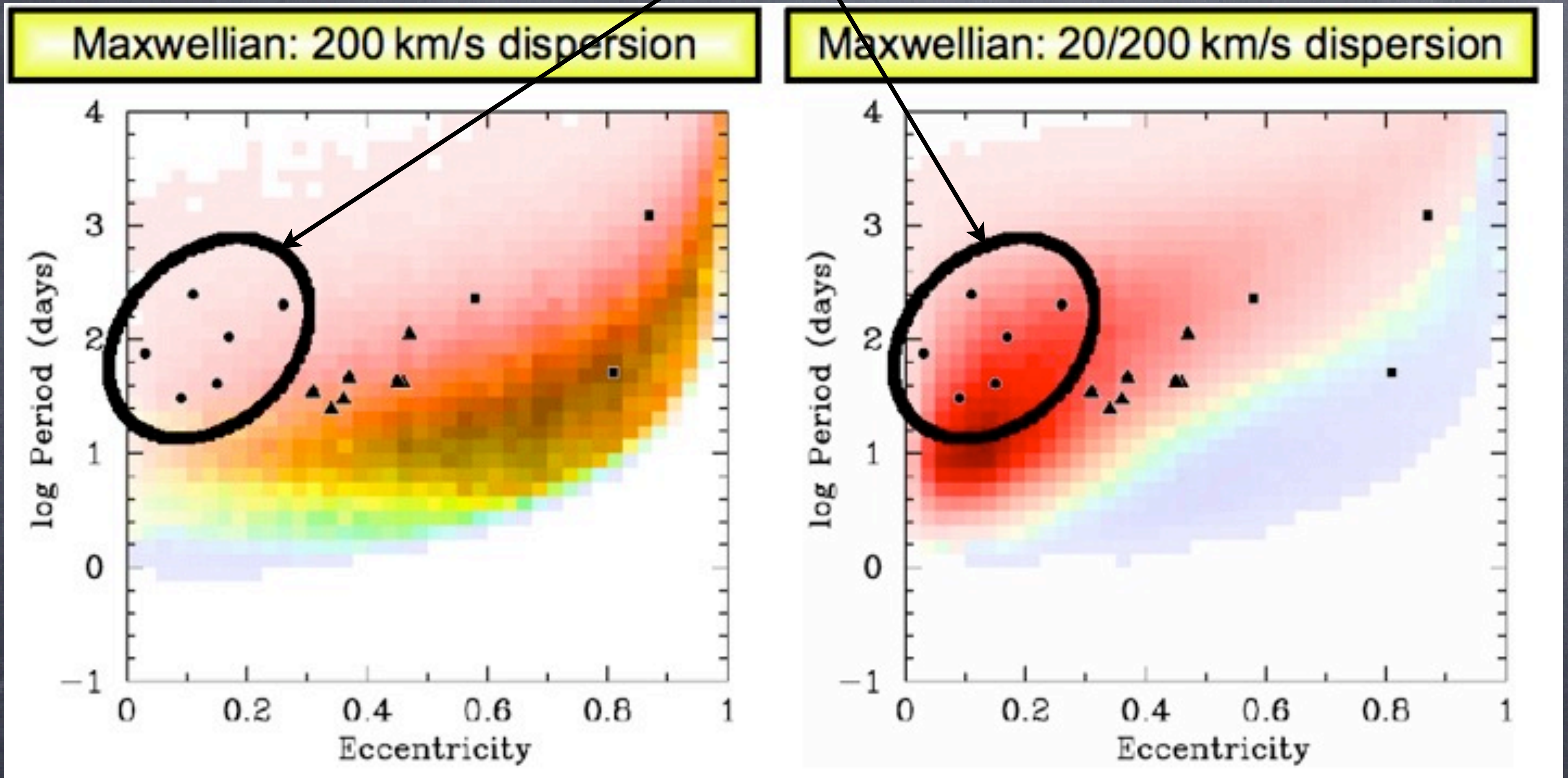
- NS retention in Globular Clusters
  (typical escape velocities of 20-50 km/s)

Pfahl et al. 2002, Kuranov & Postnov 2006, Ivanova et al. 2007

- HMXB: $e < 0.2$ and Porb > 30 days

Pfahl et al. 2004, Podsiadlowski et al. 2004

HMXB: e < 0.2 and Porb > 30 days



Pfahl et al. 2004

Podsiadlowski et al. 2004: low kicks (20km/s) from ECS events for a wide range of NS progenitors: 8 - 14 Mo

NS Kick Magnitudes

Low Kicks Favored (< 20-50 km/s) ?

- NS retention in Globular Clusters
  (typical escape velocities of 20-50 km/s)

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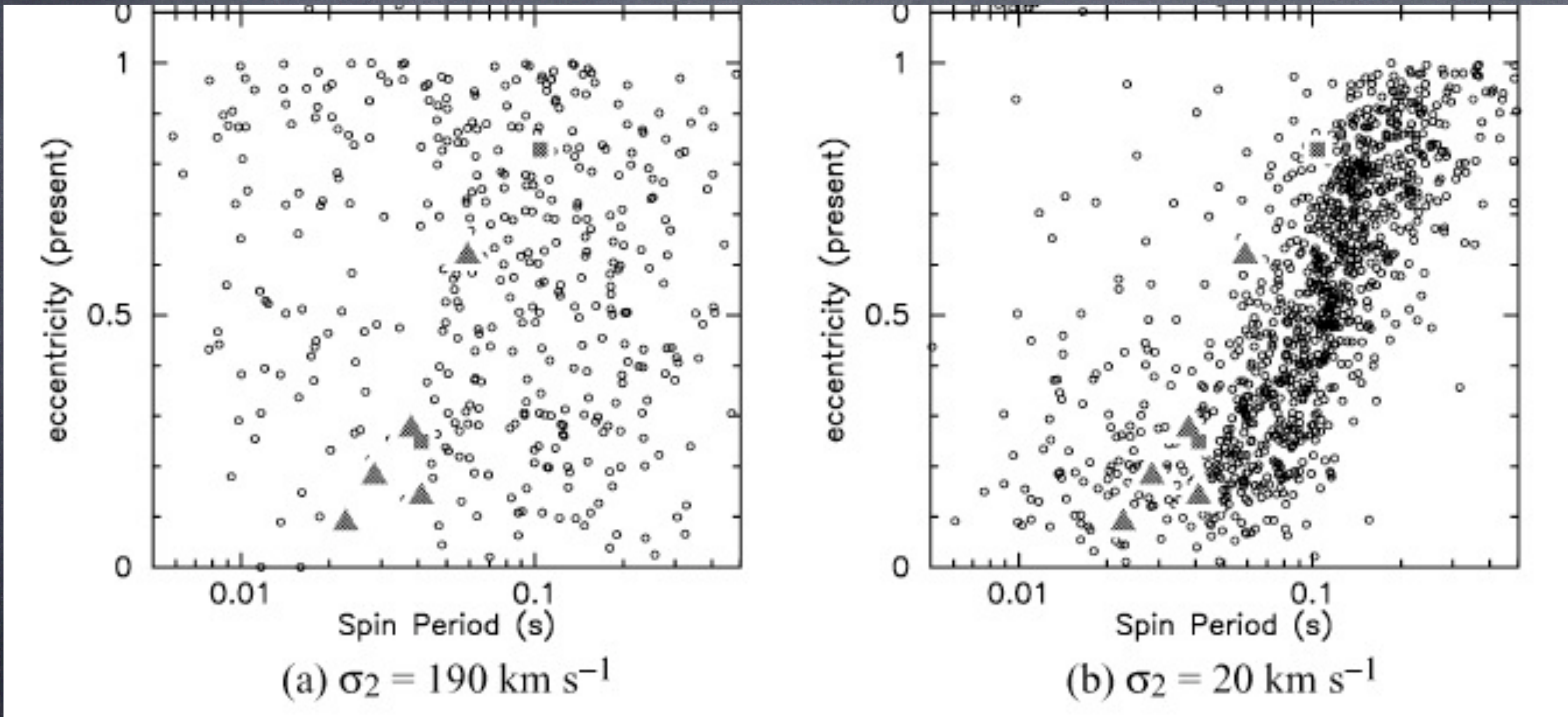
- NS-NS: spin-eccentricity (forward synthesis)

  Dewi et al. 2005

NS Kick Magnitudes

NS-NS: spin-eccentricity (forward synthesis)



NS Kick Magnitudes

Low Kicks Favored (< 20-50 km/s) ?

- NS retention in Globular Clusters
  (typical escape velocities of 20-50 km/s)

Most recent: Pfahl et al. 2002, Kuranov & Postnov 2006, Ivanova et al. 2007

- HMXB: $e < 0.2$ and Porb > 30 days

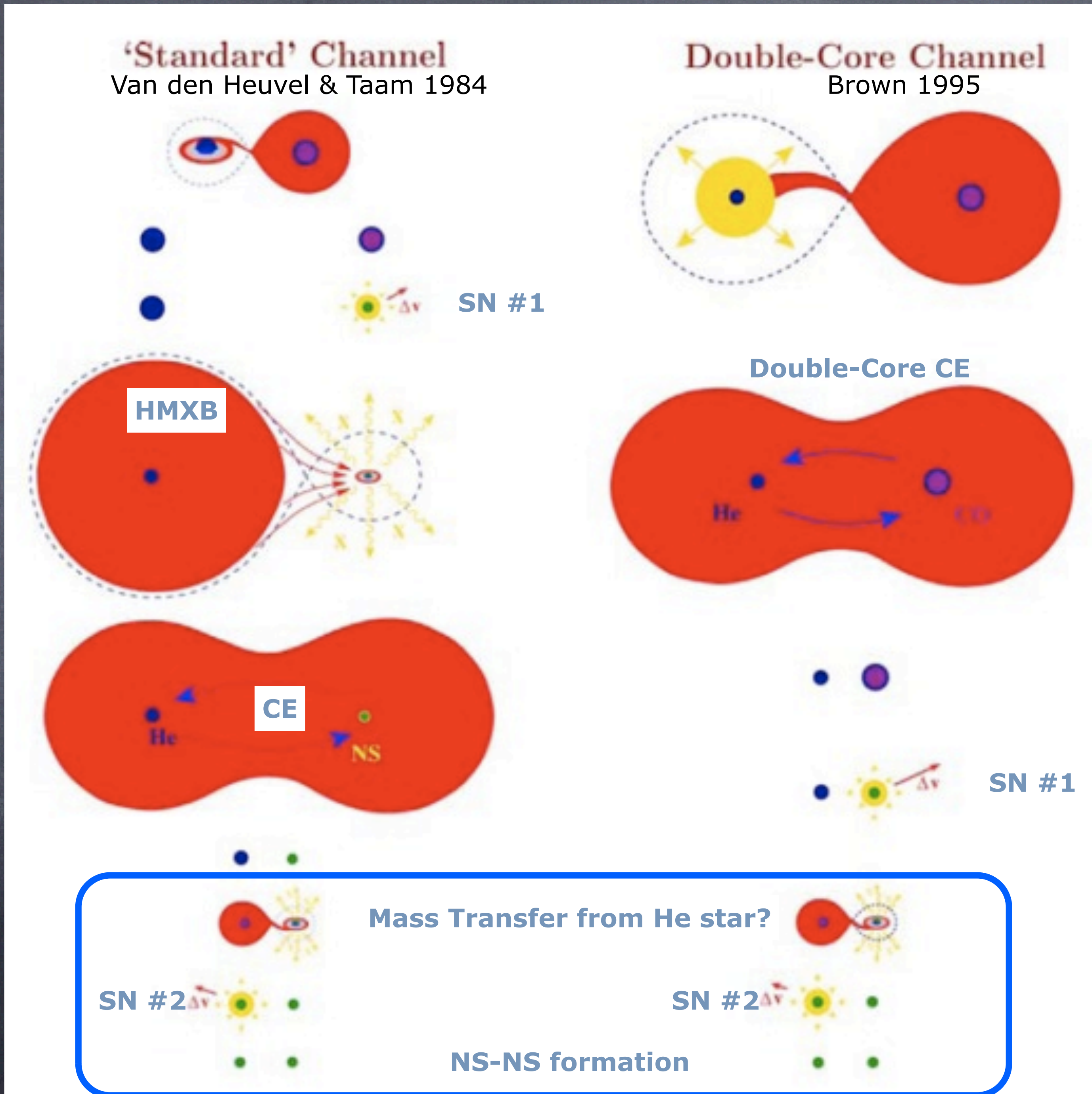
  Pfahl et al. 2004, Podsiadlowski et al. 2004

- NS-NS: spin-eccentricity (forward synthesis)

  Dewi et al. 2005

What do we learn from <u>all</u> known NS-NS systems in the Milky Way ?

2 NS-NS Formation Channels



Backwards in time: Basic Methodology

Available Observational Constraints:

- present-day orbital period, eccentricity, total mass, separation, age
- individual NS masses (in 4/8 systems)
- location in the Galaxy
- transverse velocity (in 4/8 systems)
- present-day PSR spin tilt (in 3/8 systems)
- present-day 3D orientation of the binary (in 1.5/8 systems)

Derived Constraints (on 5 independent parameters, either just ranges of values or PDFs):

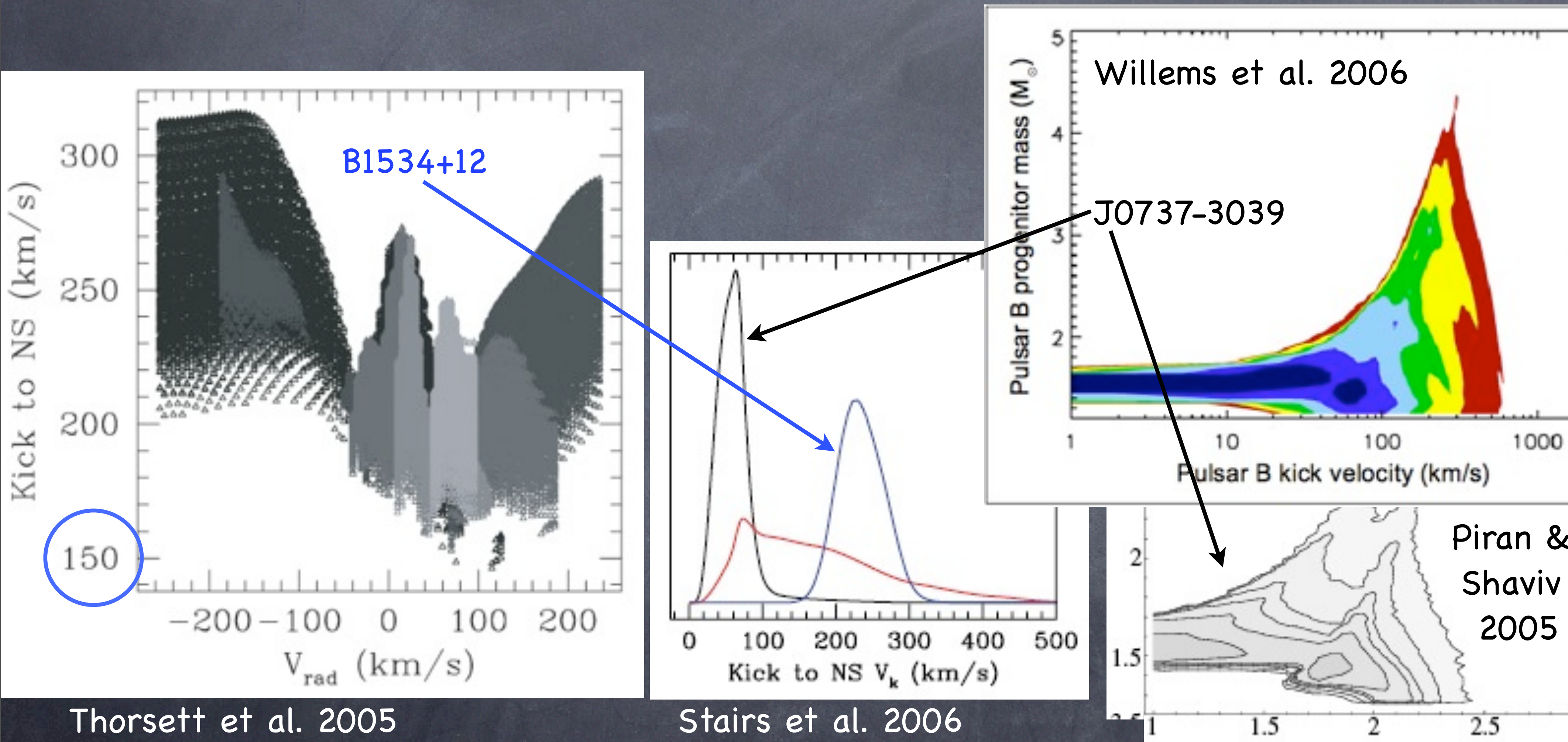
- Kick magnitude and direction
- NS #2 progenitor mass right at SN explosion
- binary separation right at SN explosion

- also on radial velocity, total velocity

Methods and Studies

	Systems	A, e, M, age	Kinematics	Galaxy Location	Vrad
Lai et al	all	yes	no	no	no
Piran & Shaviv	J0737-3039	yes	only z	only z	?
Stairs & Thorsett	B1913 +16B1534 +12J073 7- 3039	yes	yes	yes	assumed input
Wong, Willems et al	all	yes	yes	yes	self-consistent modeling

Constraints on kick magnitudes

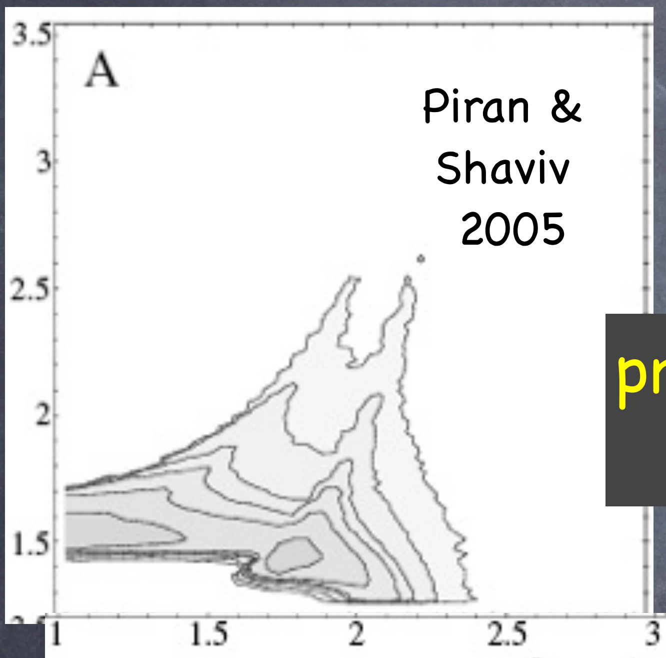


Thorsett et al. 2005

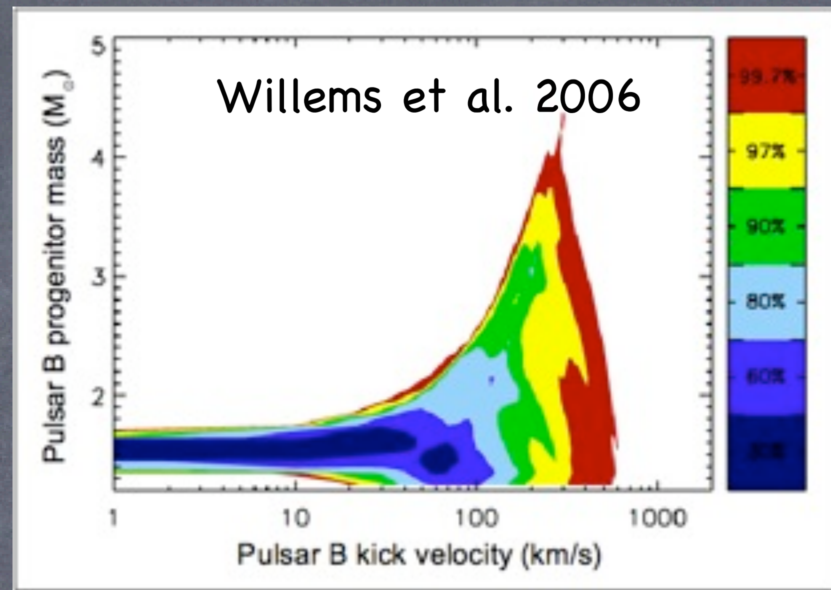
Stairs et al. 2006

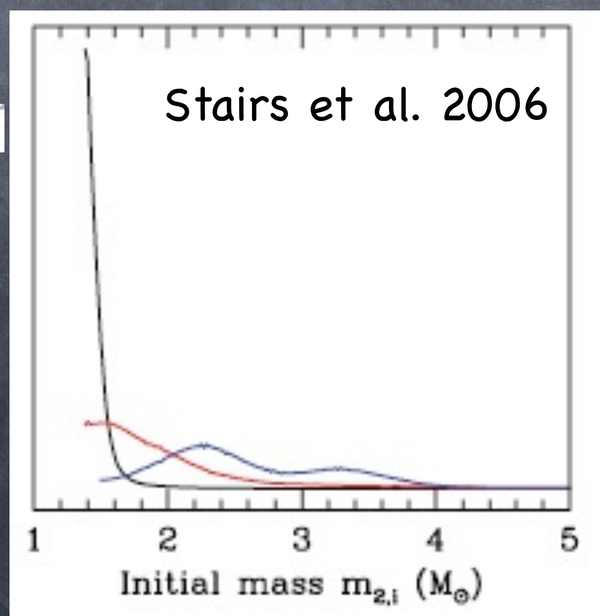
NS Progenitor Masses: Low (<2Mo) or High ?

- IF low-mass progenitors are allowed as priors, then they are:



preferred for J0737
(peak at 1.5Mo)





but NOT for B1534
(peak at 2.3Mo)

Projection effects

Example: proper motion = 30 km/s $M_{He} > 1.25\,M_\odot$
age = 0 – 100 Myr uniform V_{rad} distribution

Effect of successive marginalizations of 5-D PDF:

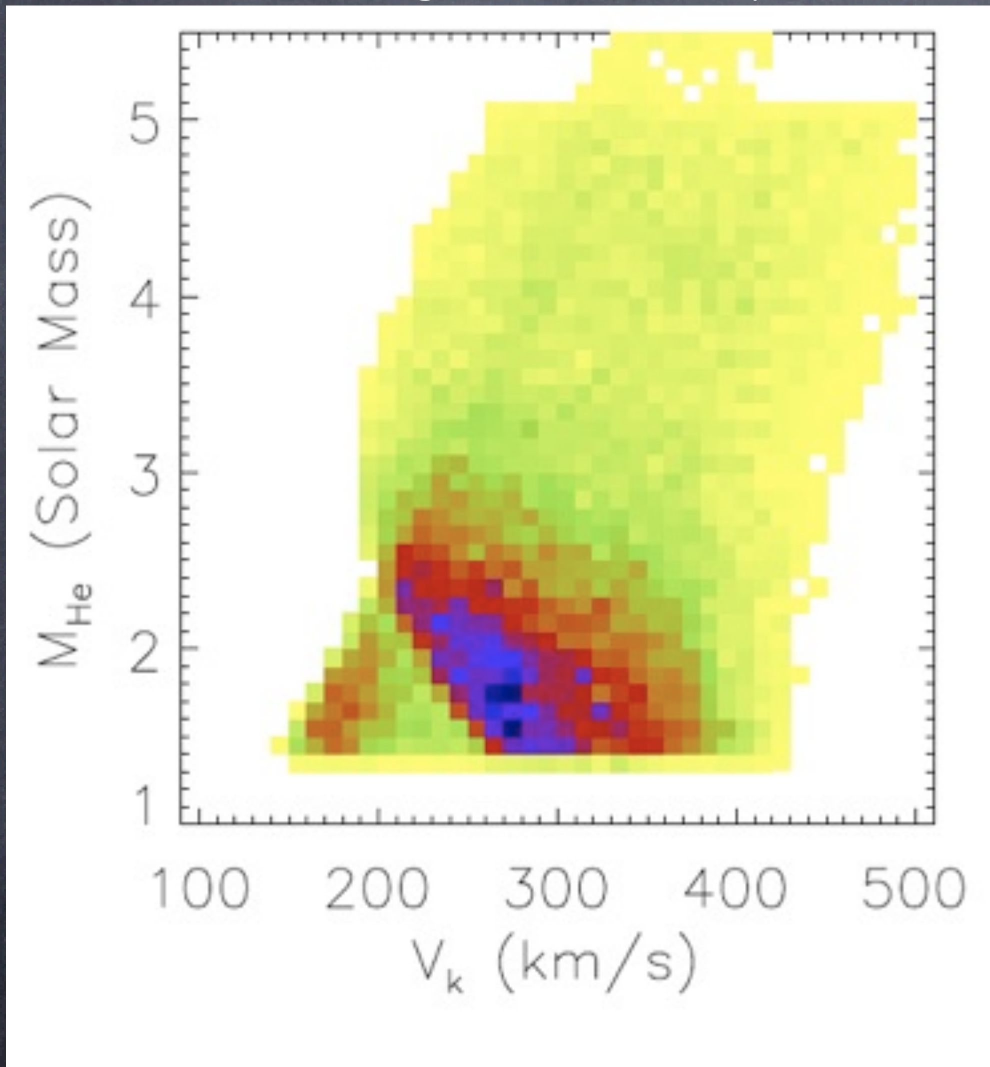
Variables	Most likely values				
	V_k	cos θ	φ	M_{He}	A
V_k, θ, φ, M_{He}, A	75 km/s	-0.025	10°	1.45 $M_\odot$	1.15 $R_\odot$
V_k, θ, φ, M_{He}	75 km/s	-0.025	[illegible]	[illegible]	
V_k, θ, M_{He}	45 km/s	[illegible]		[illegible]	
V_k, M_{He}	10 km/s			[illegible]	
V_k	55 km/s			1.45 $M_\odot$	

Projection effects can play a significant role!

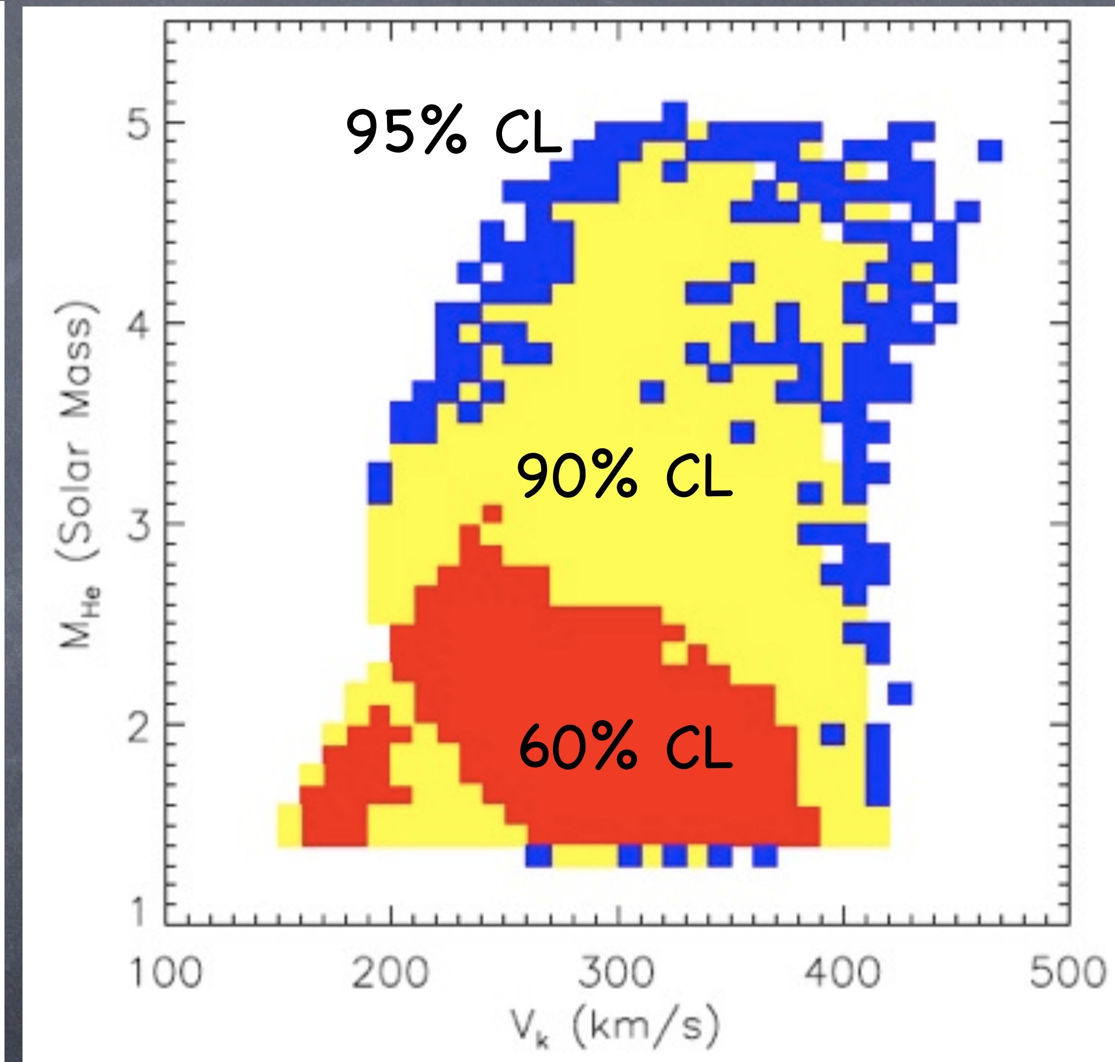
B1913+16

A = 2.8 Ro
e = 0.617

PDF scaling from the peak



Confidence Levels

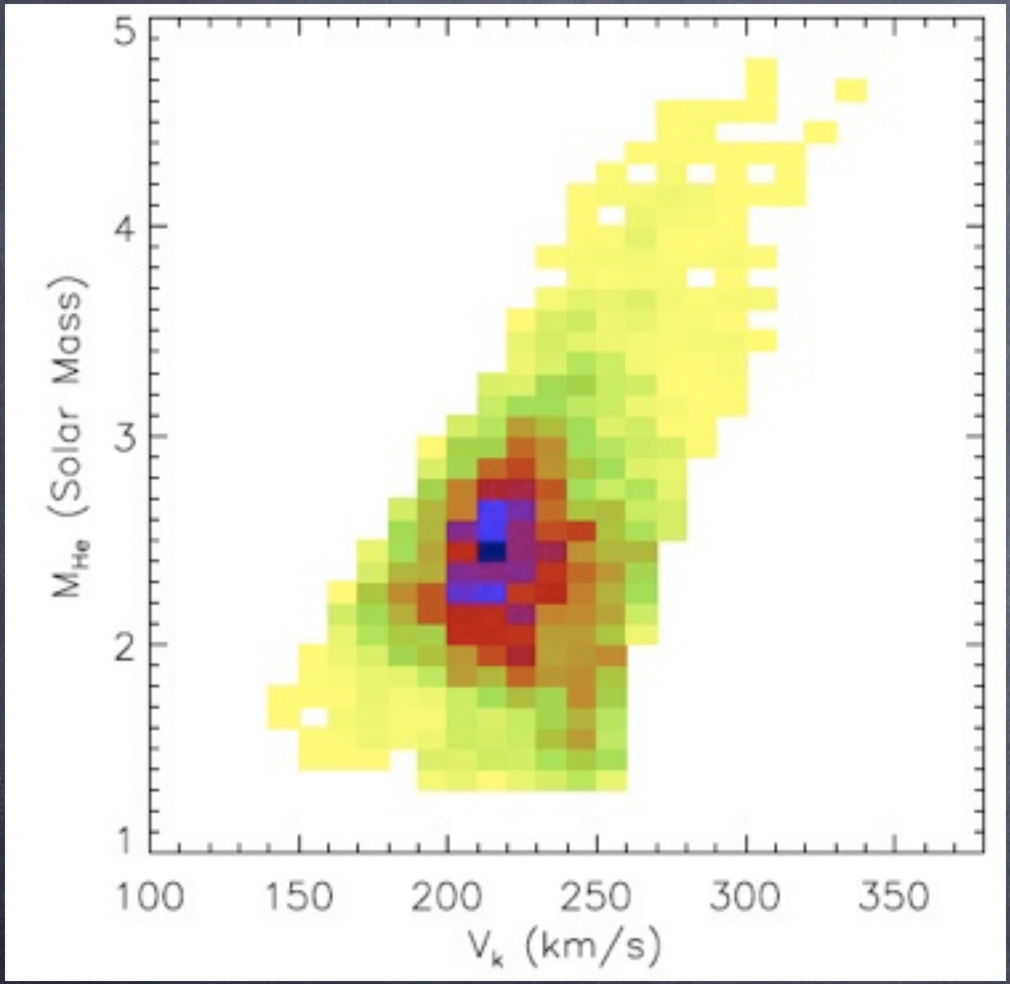


Wong, Willems, VK 2009

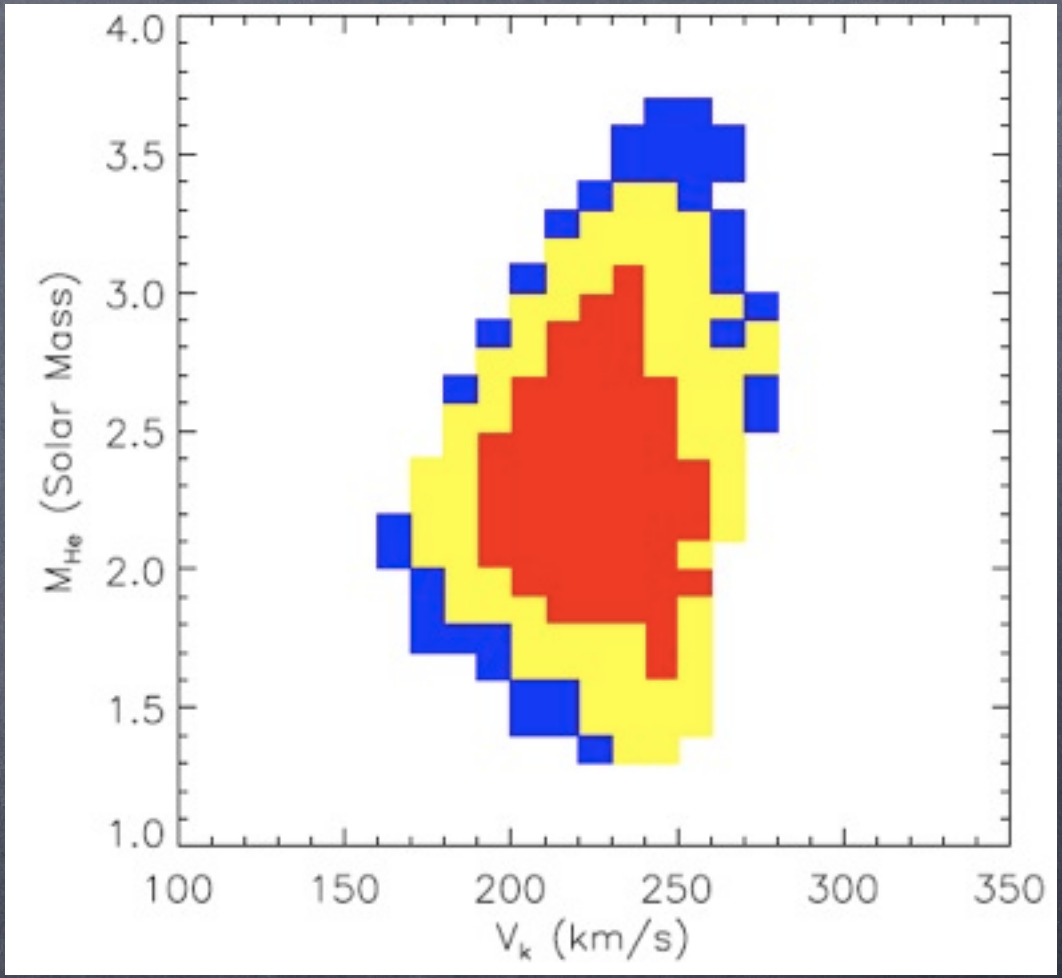
B1534+12

A = 3.28 Ro
e = 0.274

PDF scaling from the peak



Confidence Levels

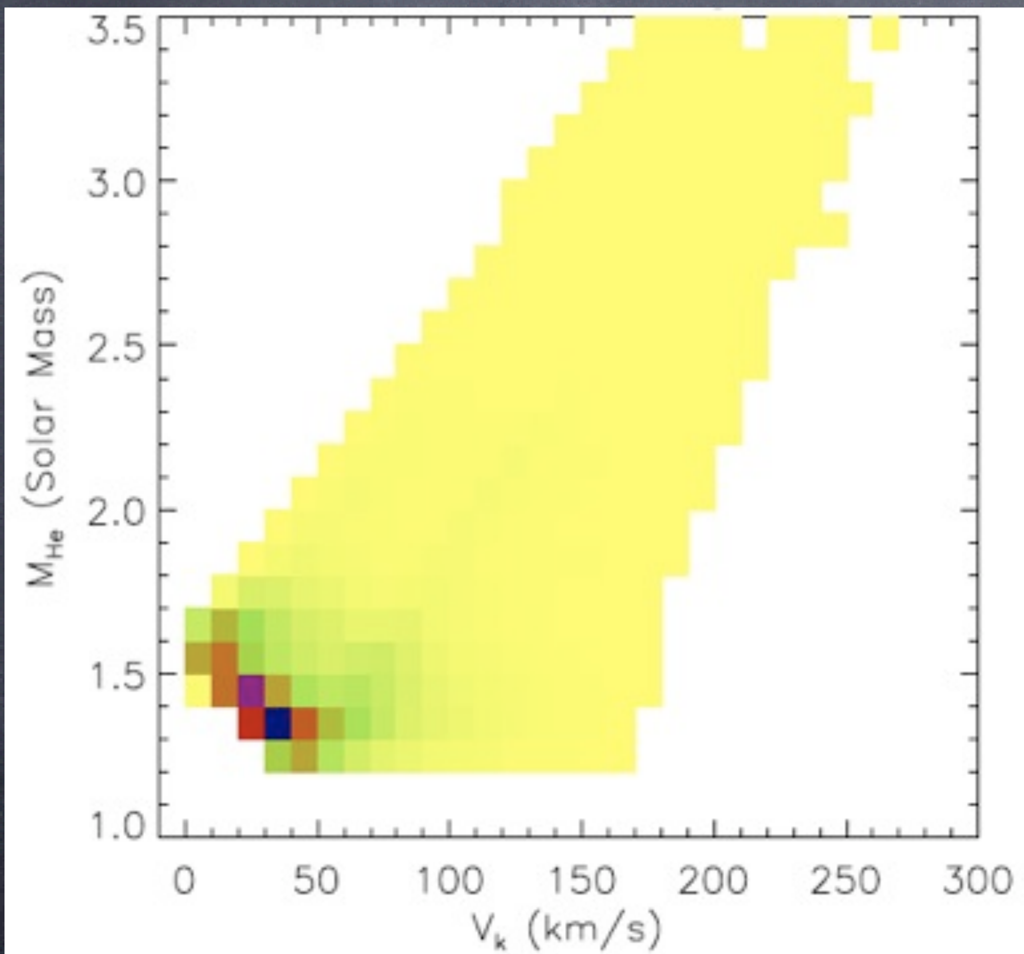


Wong, Willems, VK 2009

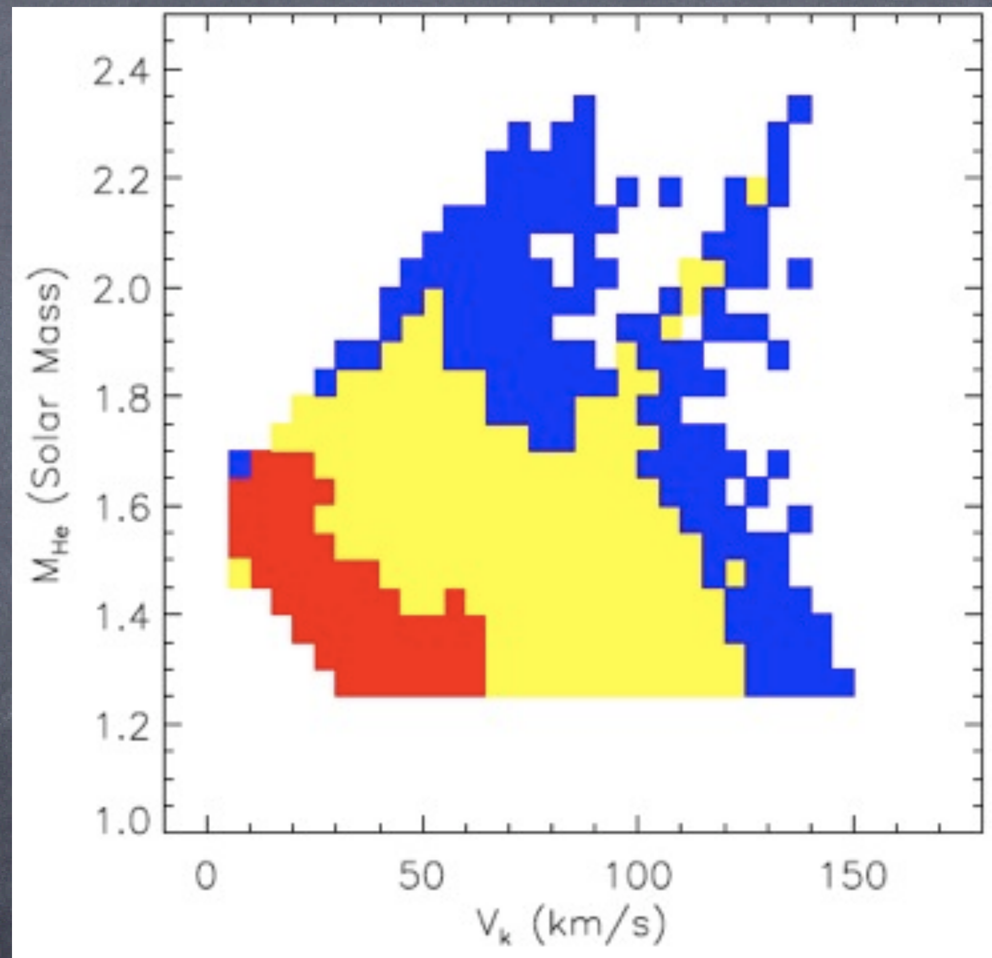
J0737-3039

A = 1.26 Ro
e = 0.088

PDF scaling from the peak



Confidence Levels

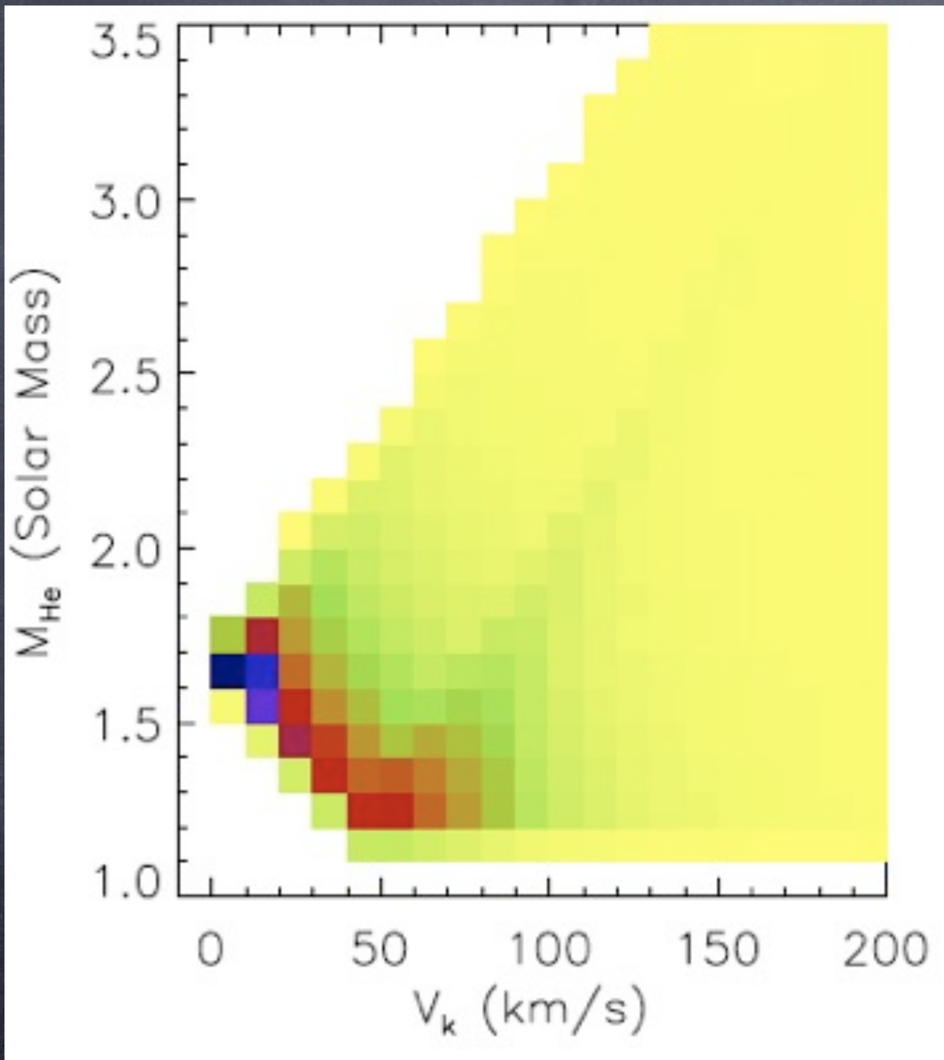


Wong, Willems, VK 2009

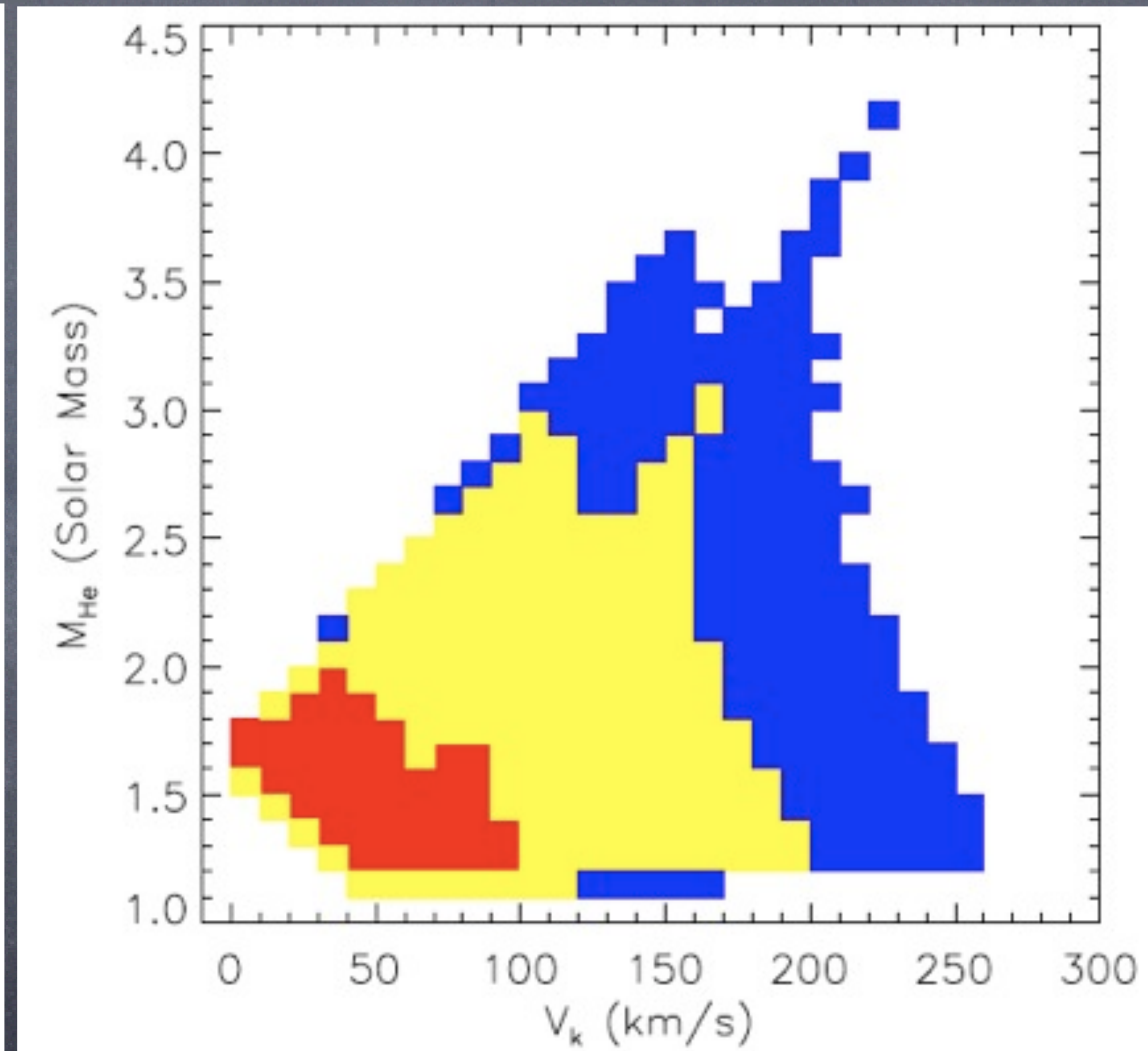
J1756-2251

A = 2.7 Ro
e = 0.18

PDF scaling from the peak



Confidence Levels

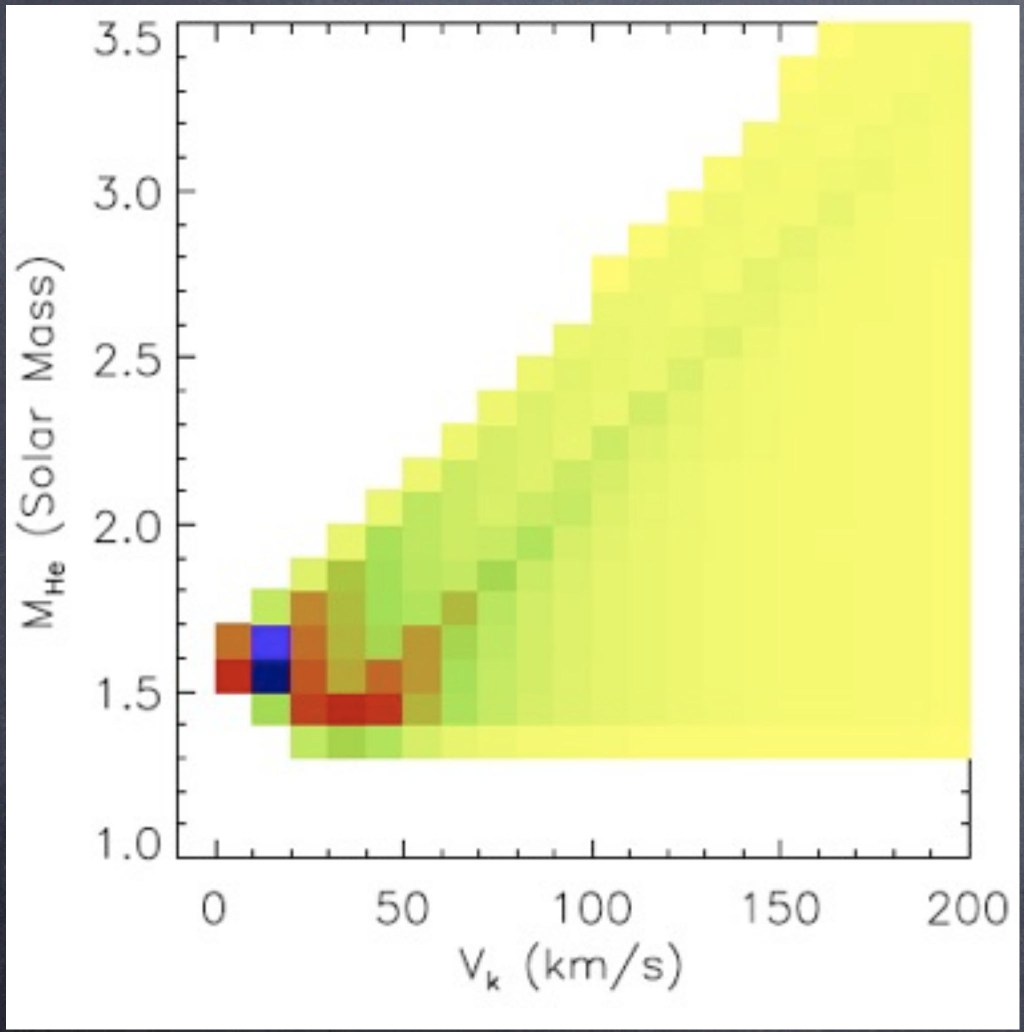


Wong, Willems, VK 2009

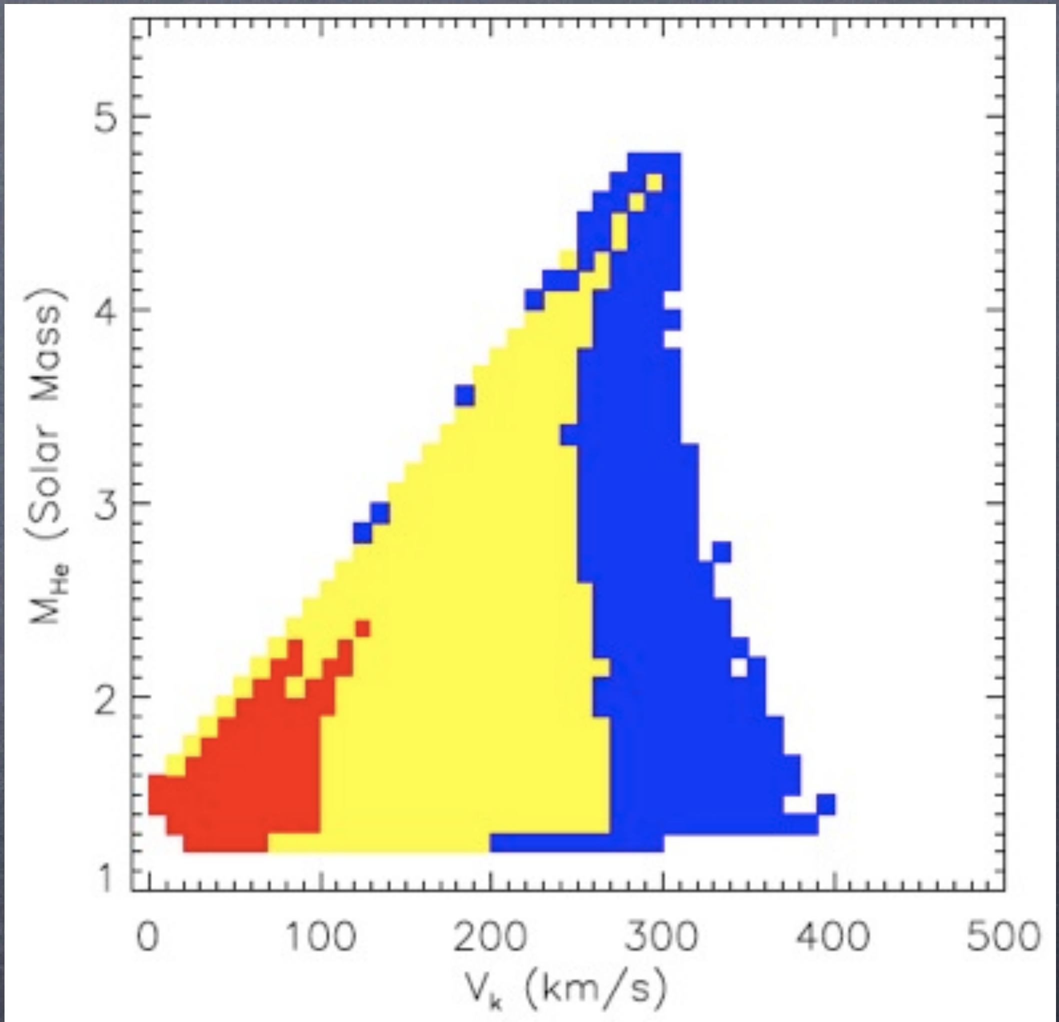
J1906+0746

A = 1.75 Ro
e = 0.085

PDF scaling from the peak



Confidence Levels

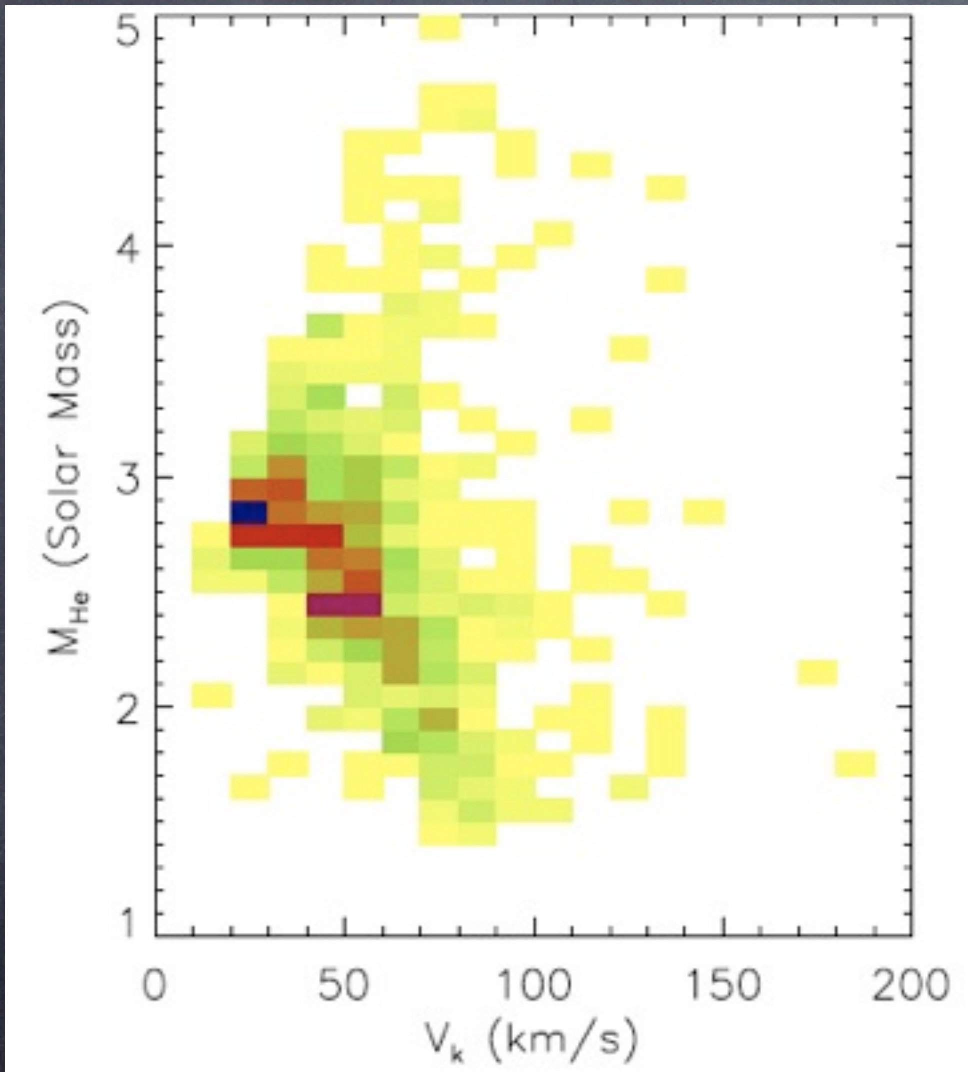


Wong, Willems, VK 2009

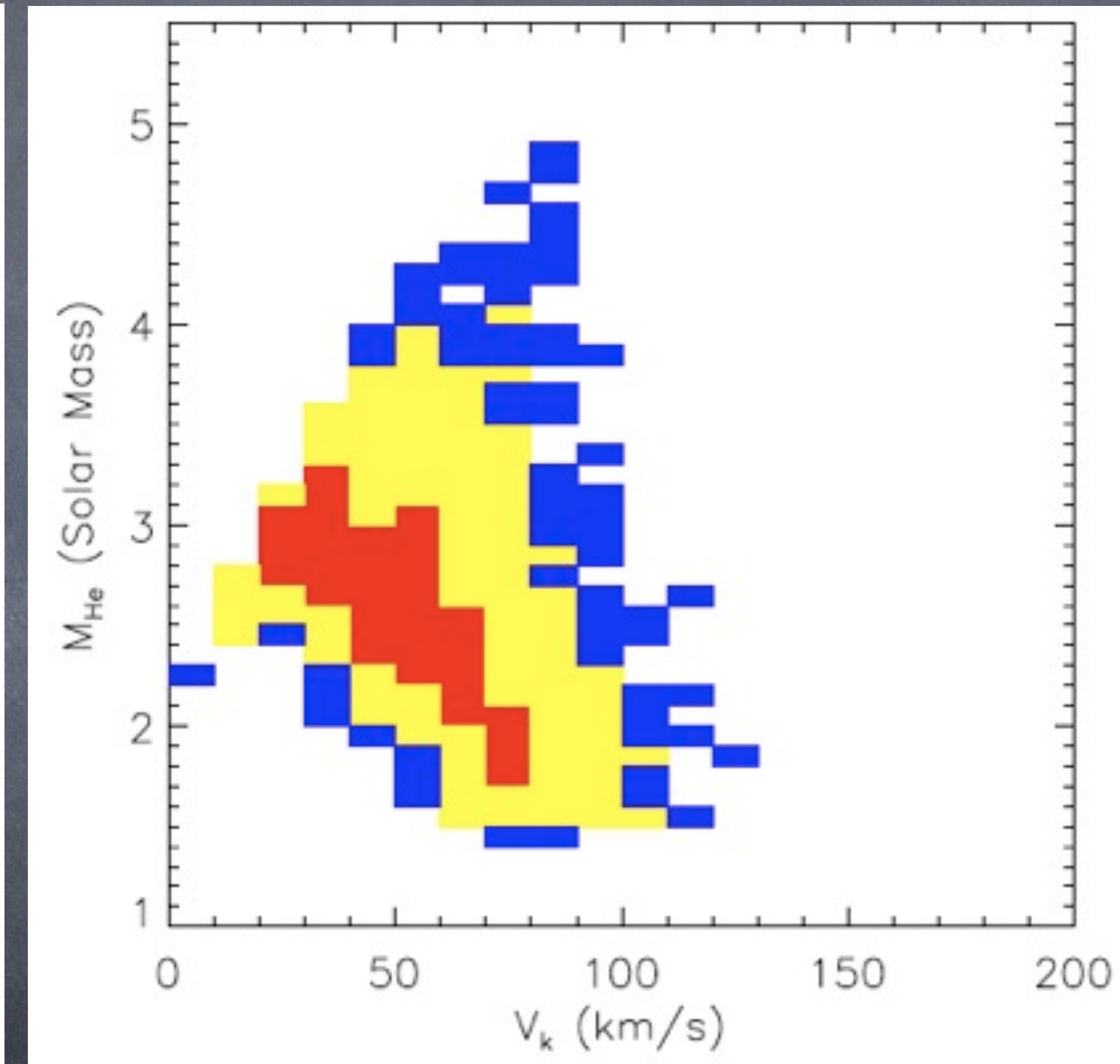
J1518+4904

A = 24.7 Ro
e = 0.25

PDF scaling from the peak



Confidence Levels

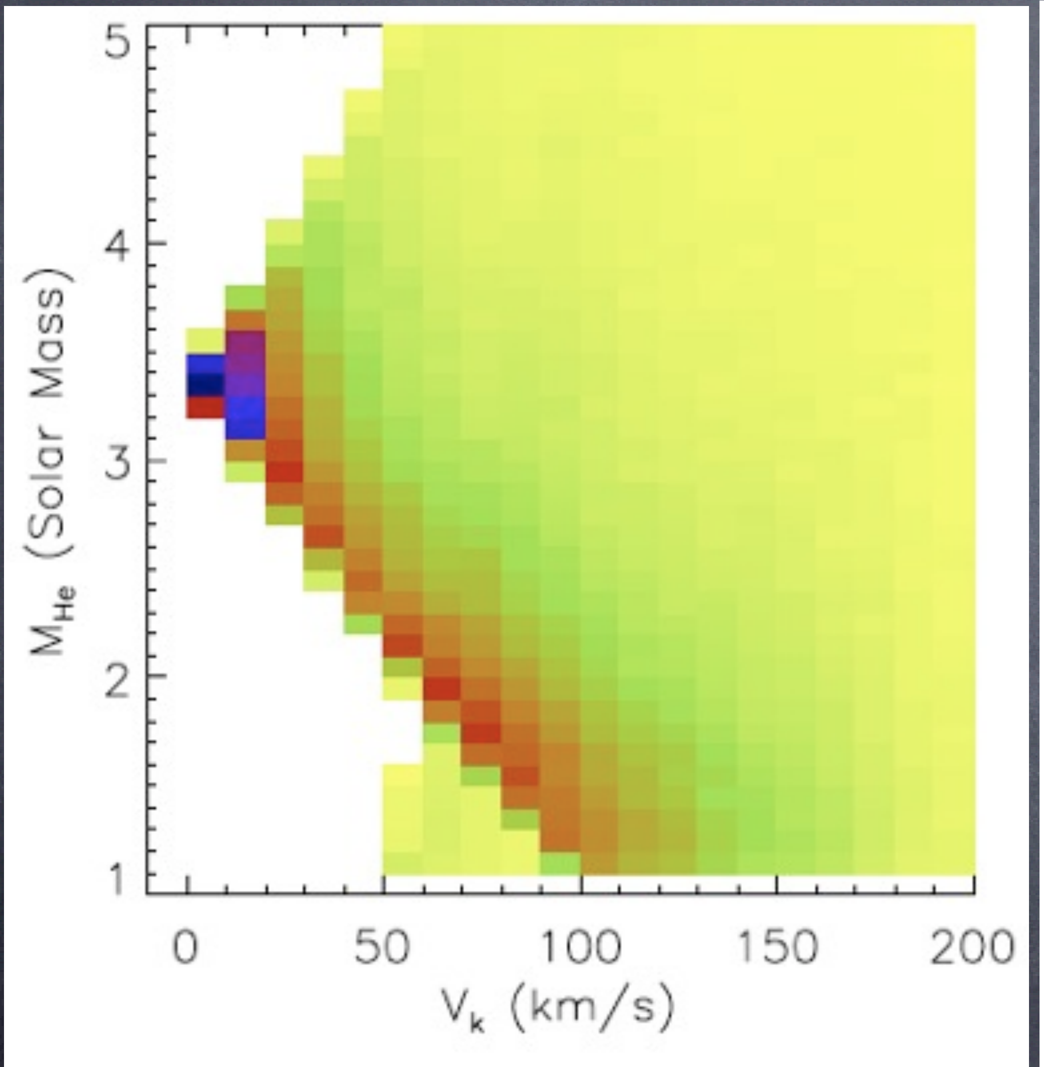


Wong, Willems, VK 2009

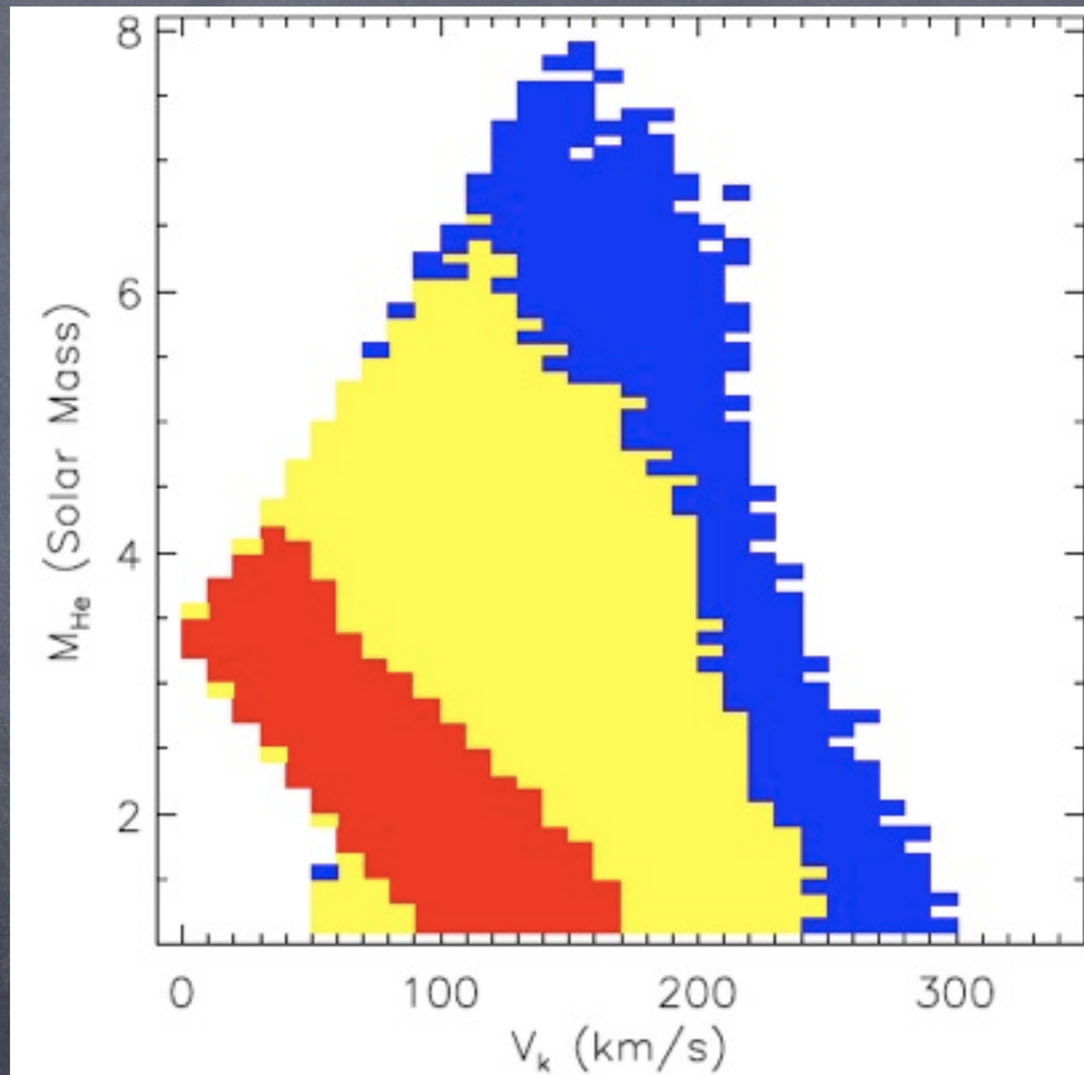
J1811-1736

A = 41.5 Ro
e = 0.828

PDF scaling from the peak



Confidence Levels

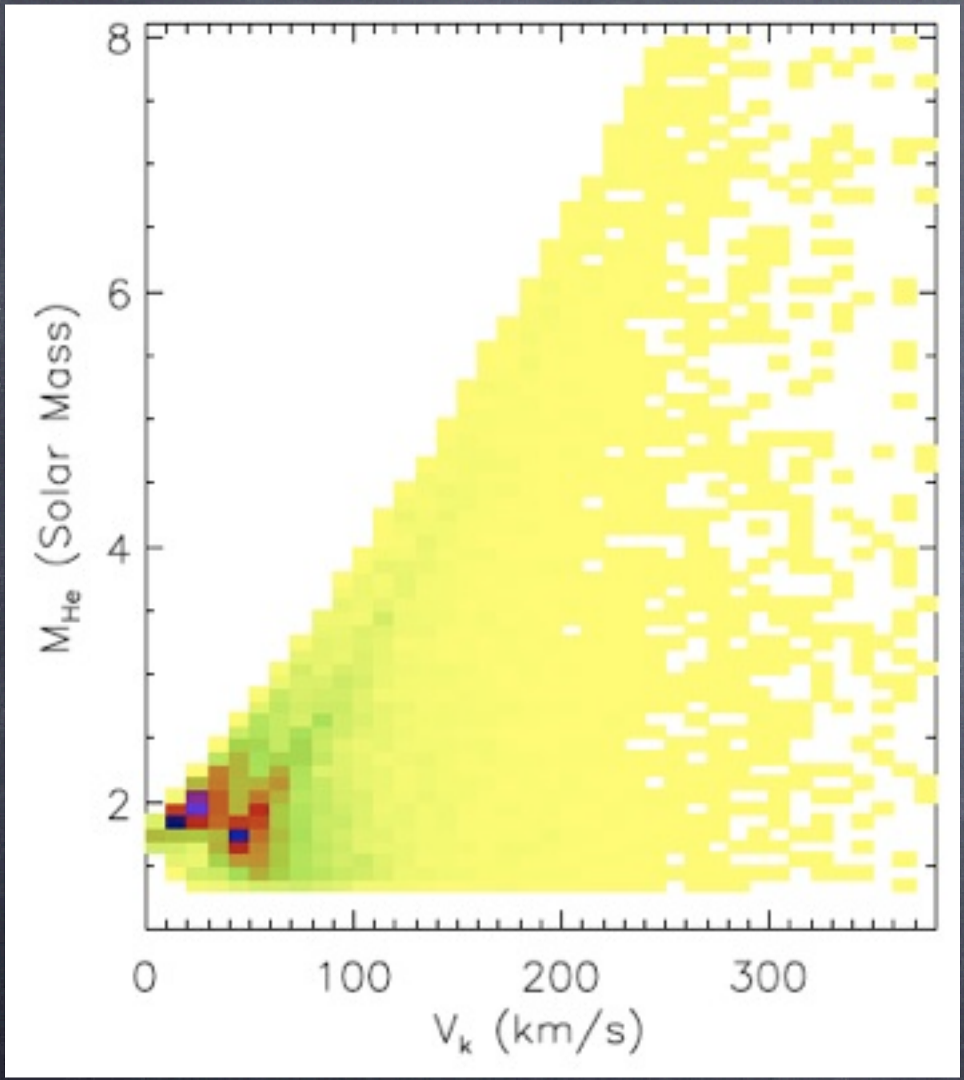


Wong, Willems, VK 2009

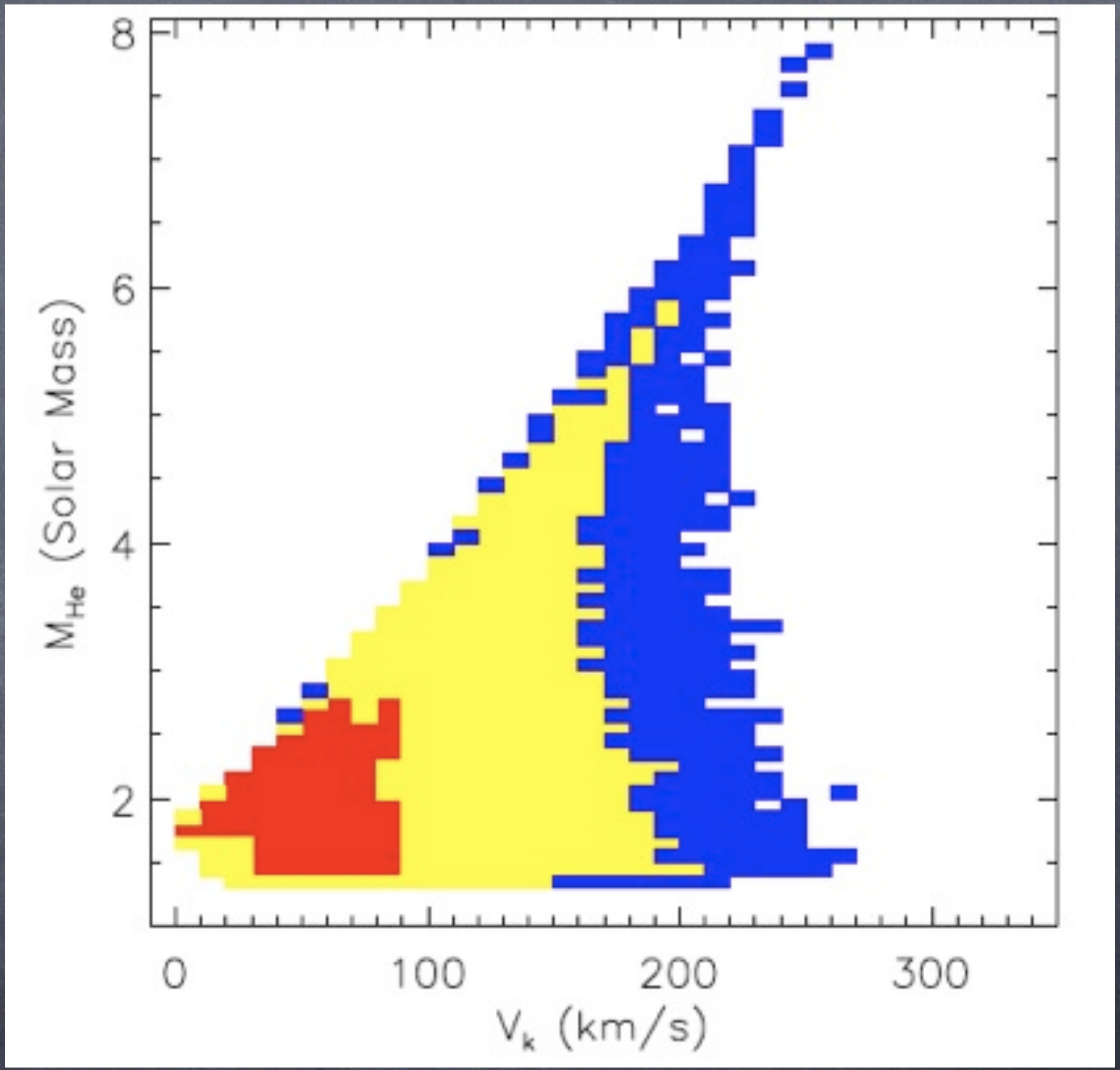
J1829+2456

A = 6.36 Ro
e = 0.14

PDF scaling from the peak

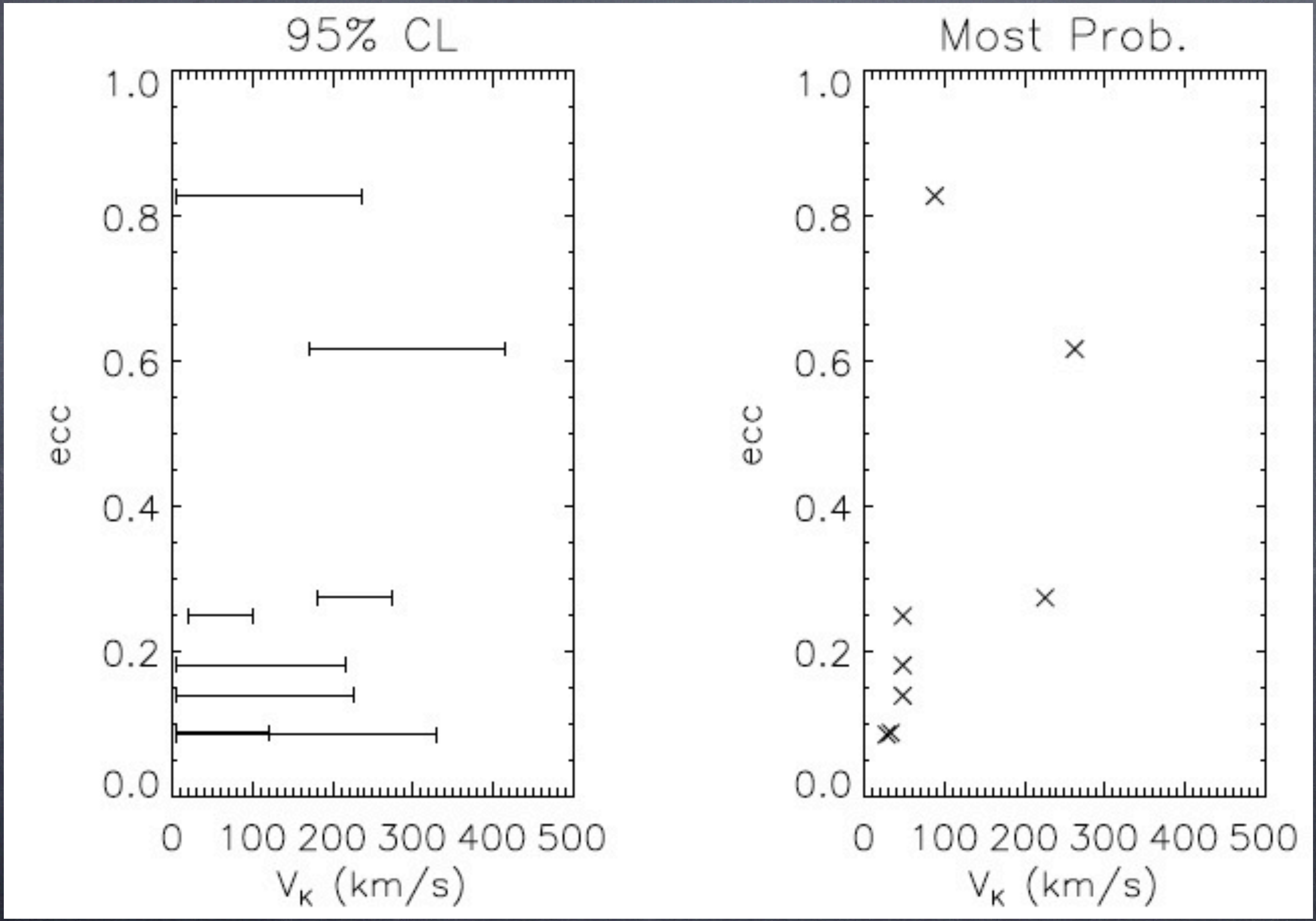


Confidence Levels



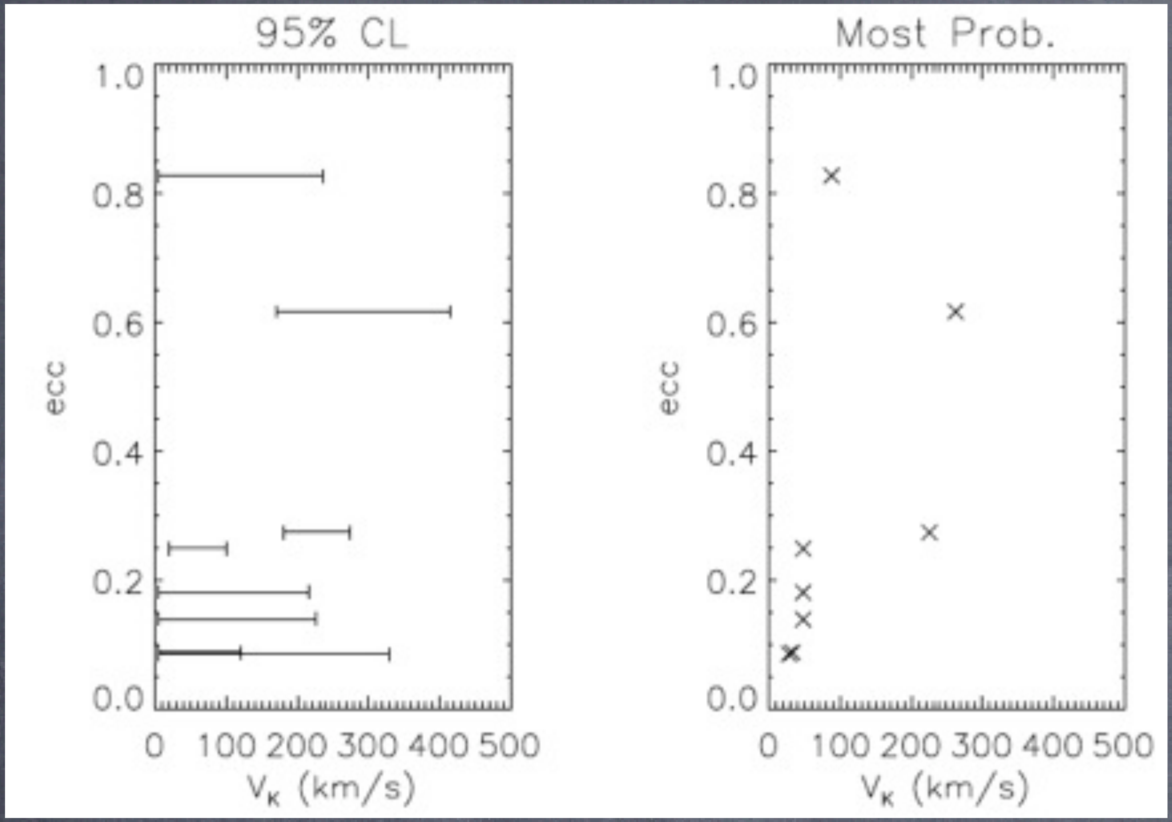
Wong, Willems, VK 2009

Low e in NS-NS: are low kicks required?



Wong, Willems, VK 2009

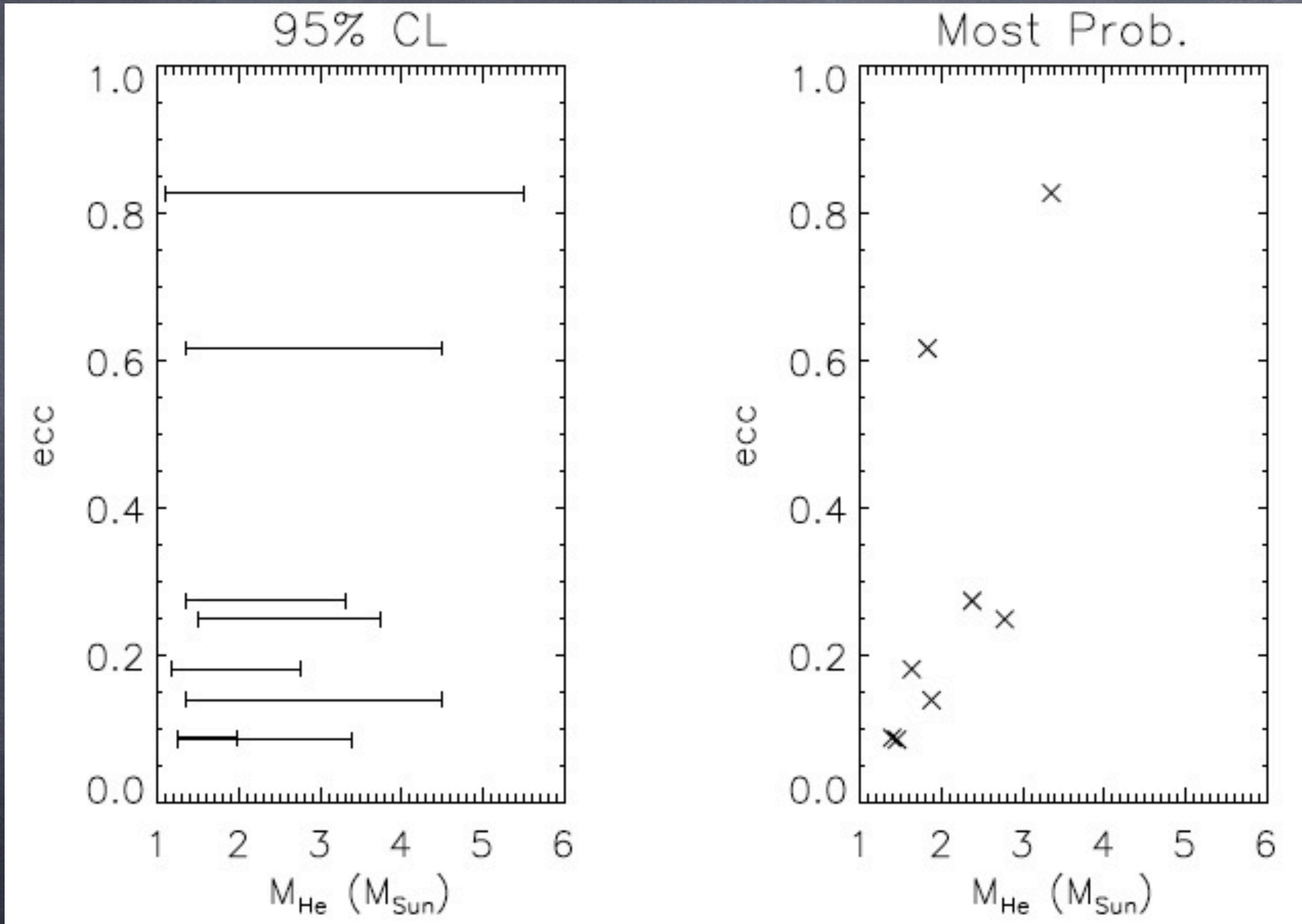
Low e in NS-NS: are low kicks required?



Stairs et al. 2006: "...the contrast between these systems [J0737-3039 (e=0.09) and B1534+12 (e=0.27)] urges caution when discussing expectations based on low kicks ..."

Wong, Willems, VK 2009

Low e in NS-NS: are low He masses required?



Wong, Willems, VK 2009

Points to take away ...

At 95% confidence level:

- only 0737 has progenitor masses below 2 Msun, and hence potentially clearly connected to ECS events

- only 0737 and 1518 have kick magnitudes below 120 km/s, and hence potentially clearly connected to ECS events

- only 1913 and 1534 have kick magnitudes above 170 km/s, and hence potentially clearly connected to Fe-core SN

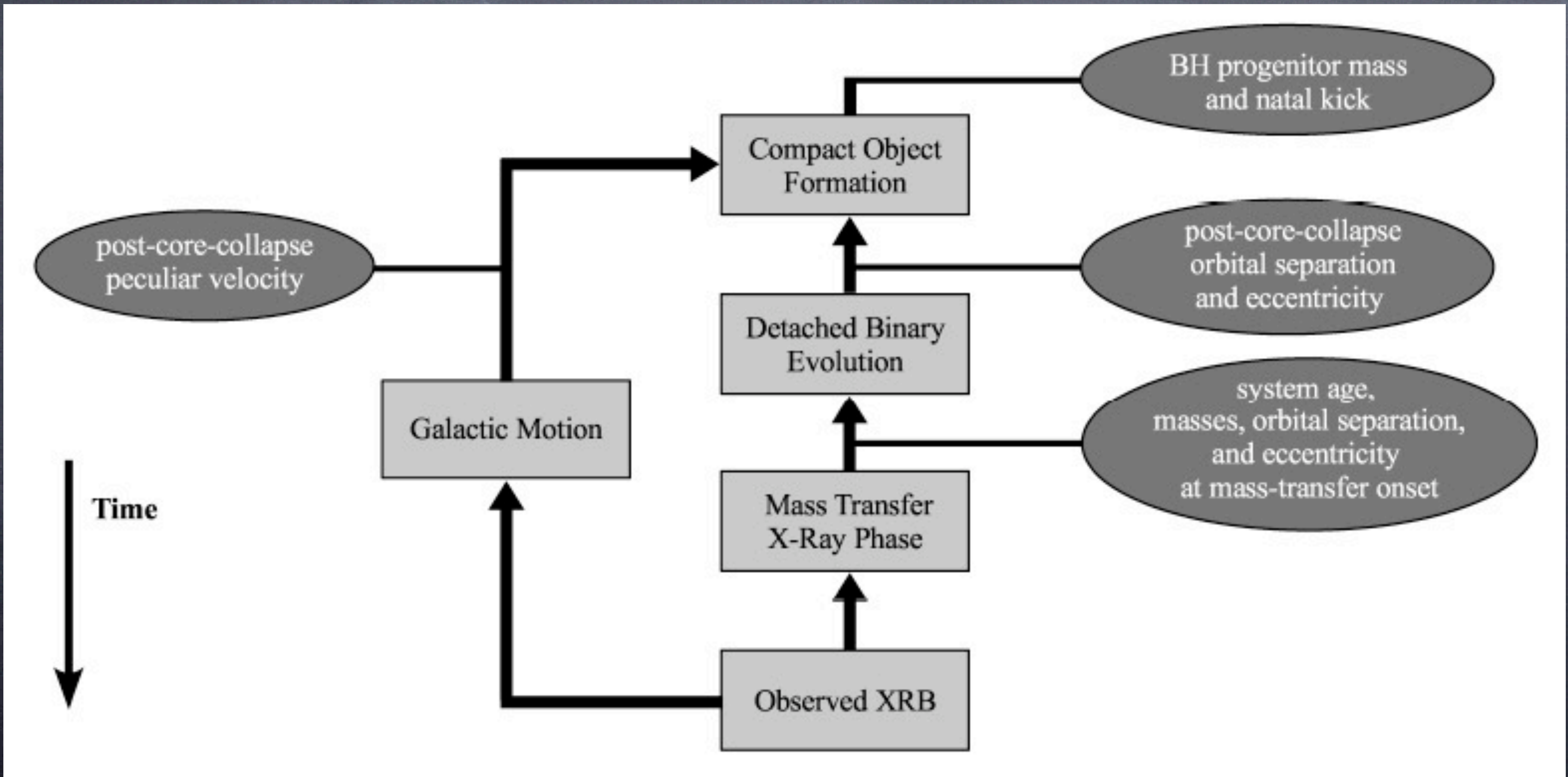
- Low e values of known NS-NS do NOT ALWAYS require low kicks
  see B1534 and J0737
  or low He progenitor masses

BEYOND THE BASICS

Turn Clock Backwards

BEYOND THE BASICS

For Accreting BH in X-Ray Binaries



Willems, Fragos, et al

BEYOND THE BASICS

Turn Clock Backwards

BEYOND THE BASICS

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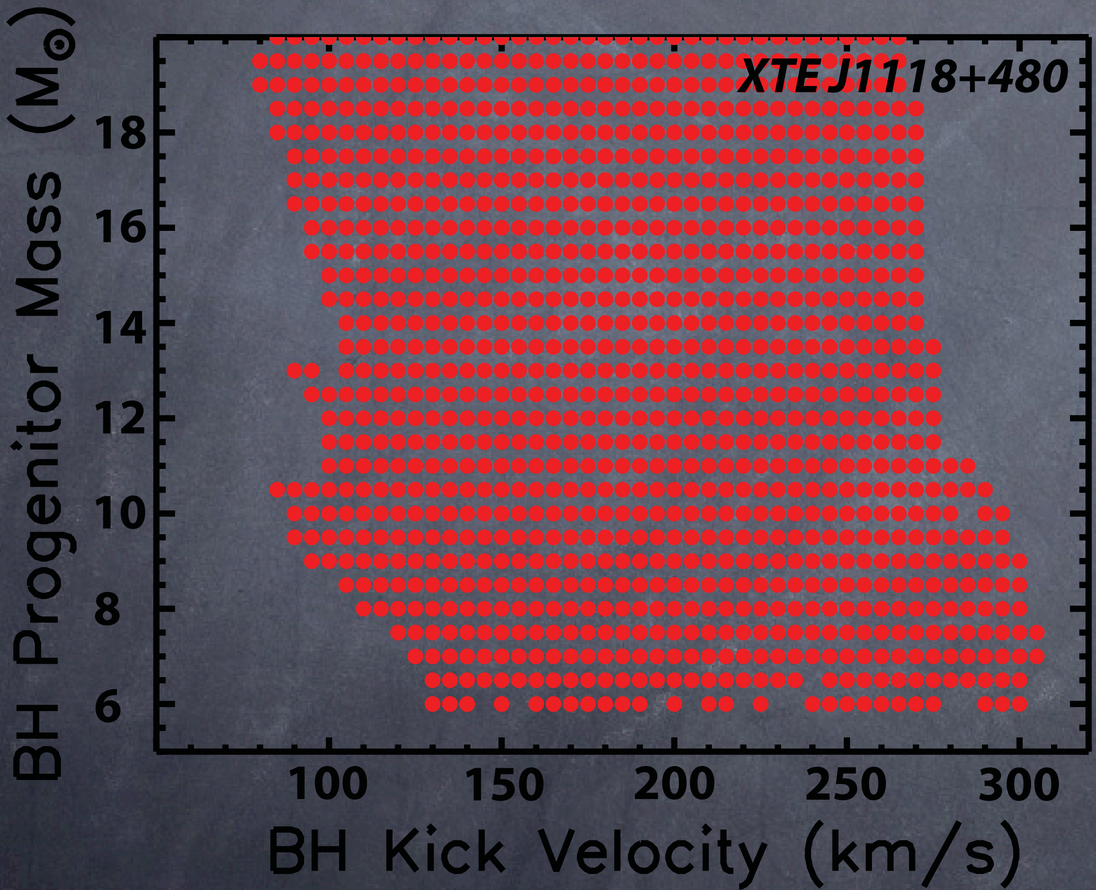


Newborn black hole

6 – 10 $M_\odot$

Black hole natal kick

80 – 310 km/s

Initial donor

1 – 1.6 $M_\odot$

The black hole formed 1.5 to 7 billion years ago

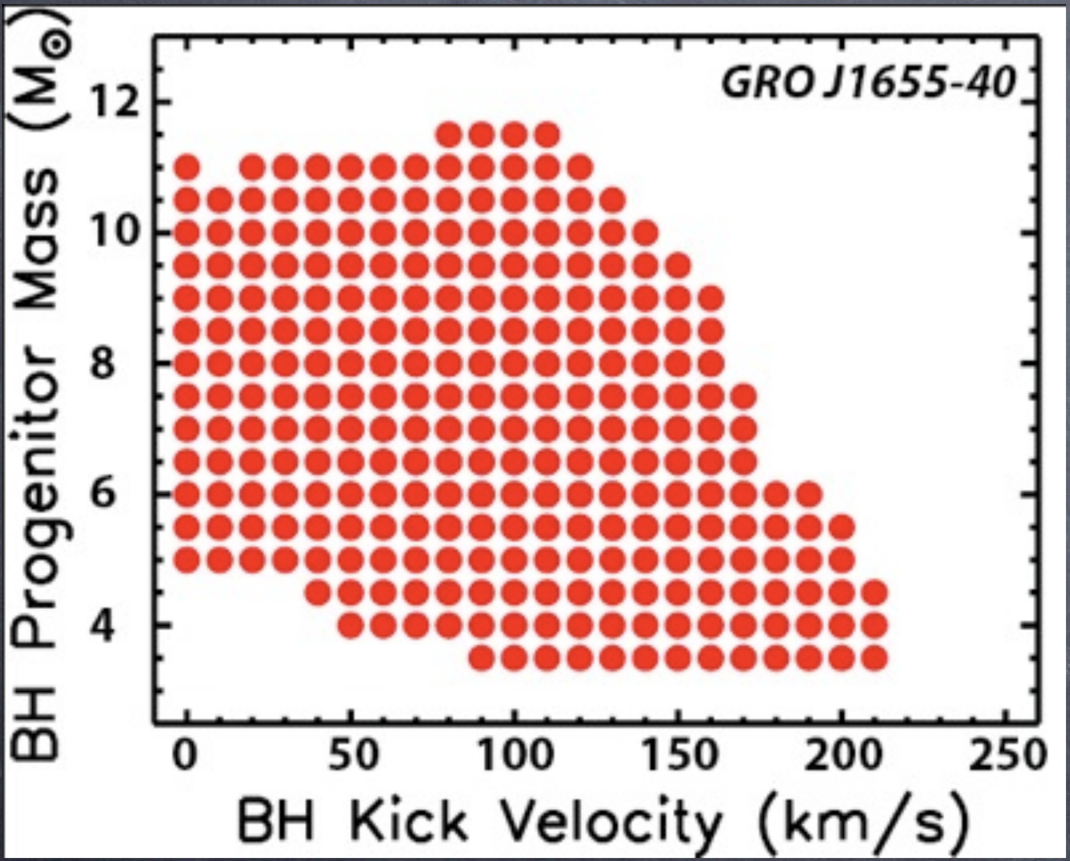
Fragkos et al 2008

BEYOND THE BASICS

Turn Clock Backwards

BEYOND THE BASICS

For Accreting BH in X-Ray Binaries



Black hole progenitor

$4 - 12\,M_\odot$

Initial black hole mass

$3.5 - 6.3\,M_\odot$

Black hole natal kick

$0 - 210\,\mathrm{km/s}$

Black Hole Kick: possible, but not required

The black hole was formed 0.3 to 1 billion years ago

Willems et al 2005

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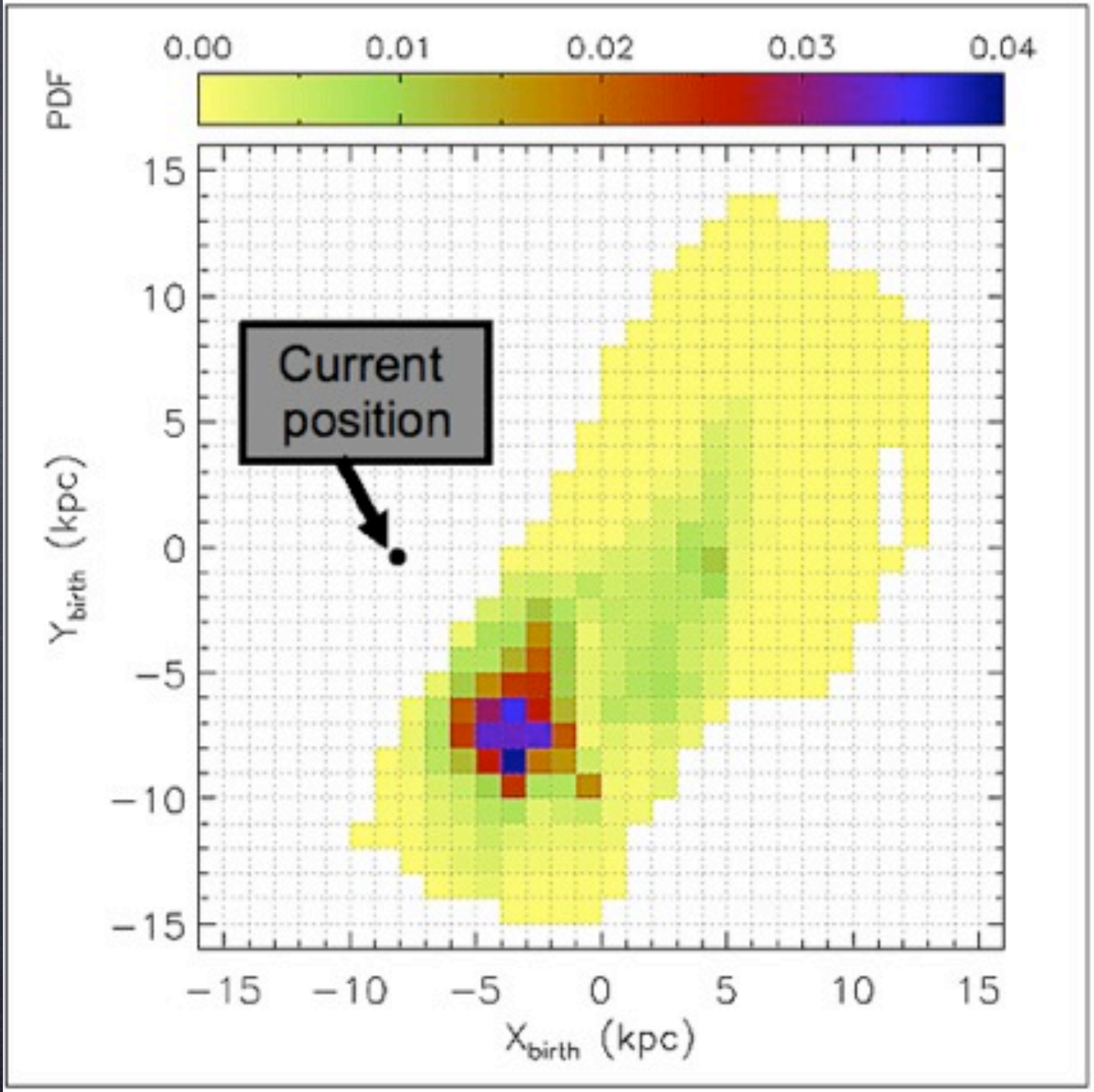
Current Constraints

	J0737 (15deg)	B1534	B1913	J1518	J1756	J1811	J1829	J1906
vk (60%)	10 - 50	205 - 245	210 - 325	30 - 65	5 - 70	25 - 125	10 - 80	5 - 100
vk (90%)	5 - 95	190 - 270	190 - 400	20 - 85	5 - 160	5 - 190	5 - 175	5 - 255
vk (95%)	5 - 120	180 - 275	170 - 415	20 - 100	5 - 215	5 - 235	5 - 225	5 - 330
vk (all)	5 - 330	145 - 640	145 - 1620	5 - 335	5 - 1195	5 - 865	5 - 855	5 - 1200
M_{He} (60%)	1.250 - 1.500	1.85 - 2.65	1.40 - 2.40	2.35 - 3.15	1.30 - 1.80	1.60 - 3.50	1.50 - 2.30	1.25 - 1.75
M_{He} (90%)	1.250 - 1.750	1.50 - 3.15	1.35 - 4.05	1.60 - 3.45	1.15 - 2.30	1.10 - 4.55	1.35 - 3.55	1.25 - 2.85
M_{He} (95%)	1.225 - 1.975	1.35 - 3.30	1.35 - 4.50	1.50 - 3.75	1.15 - 2.75	1.10 - 5.50	1.35 - 4.50	1.25 - 3.40
M_{He} (all)	1.225 - 4.650	1.35 - 5.60	1.35 - 8.00	1.45 - 7.85	1.15 - 8.00	1.10 - 8.00	1.35 - 8.00	1.20 - 4.80
V_t (60%)	21.0 - 30.0	115.50 - 122.25	113 - 142	24.8 - 29.0	8 - 44	25 - 108	8 - 57	91 - 165
V_t (90%)	17.5 - 31.0	115.50 - 126.00	115 - 160	22.0 - 28.6	1 - 96	8 - 168	1 - 120	44 - 266
V_t (95%)	18.0 - 32.5	116.00 - 127.25	111 - 158	21.8 - 28.6	1 - 133	3 - 201	1 - 155	25 - 316
V_t (all)	17.0 - 33.0	115.25 - 127.25	110 - 160	21.6 - 29.0	0 - 628	0 - 655	0 - 493	0 - 586
V_r (60%)	10 -- 55	-85 -- 30	-115 - 35	-30 - 10	-40 - 35	10 -- 120	-35 -- 25	25 -- 100
V_r (90%)	-20 -- 75	-140 -- 80	-175 - 160	-55 -- 35	-110 - 85	-55 - 180	-100 - 65	-70 -- 180
V_r (95%)	-25 -- 105	-160 -- 105	-170 - 220	-80 -- 35	-150 - 115	-90 -- 210	-140 - 75	-120 -- 215
V_r (all)	-125 -- 455	-345 -- 285	-575 - 220	-255 - 165	-455 - 370	-505 - 400	-520 - 190	-580 -- 270
**Tot V_{sys} (60%)	195 - 245	255 - 360	225 - 360	210.0 - 245.0	195 - 255	160 - 250	195 - 260	190 - 265
**Tot V_{sys} (90%)	175 - 275	130 - 355	120 - 400	195.0 - 257.5	155 - 305	105 - 300	155 - 325	150 - 365
**Tot V_{sys} (95%)	170 - 295	120 - 365	80 - 420	187.5 - 262.5	130 - 335	90 - 330	135 - 360	165 - 425
**Tot V_{sys} (all)	15 - 375	85 - 445	15 - 650	130.0 - 342.5	0 - 715	0 - 675	15 - 630	0 - 425

Double pulsar birth place



Example:

proper motion: 30 km/s

Gaussian V_{rad}: 130 km/s

age: 30 – 70 Myr

The system may be several kpc away from where it was formed