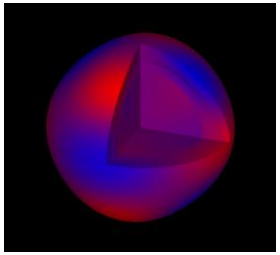
The Impact of Asteroseismology across Stellar Astrophysics

KITP October 2011



The Empirical Mass Distribution of Hot B Subdwarfs derived by asteroseismology and other means

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Hot (T_{eff} = 20 000 - 40 000 K) and compact (log g = 5.2 - 6.2) stars belonging to Extreme Horizontal Branch (EHB)

ore (I), radiative He mantle (II) and very thin H-r

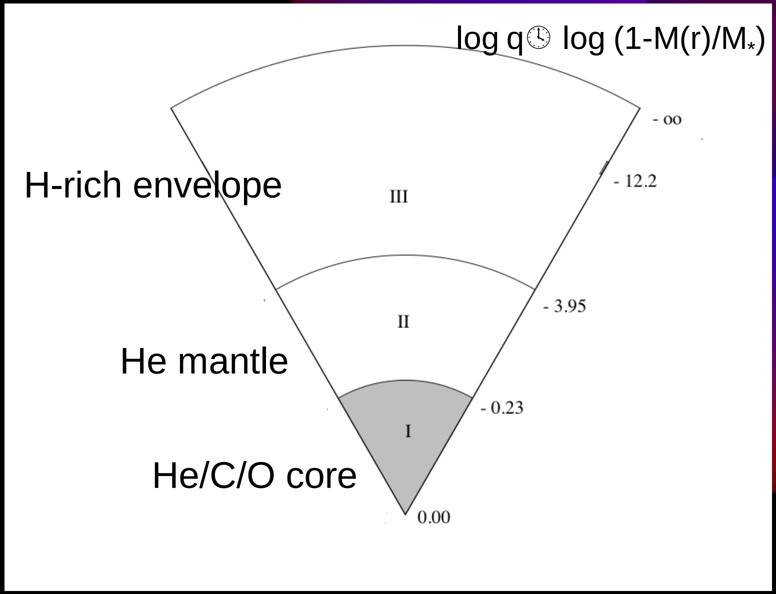
Myr) on EHB, then evolve as low-mass white dwar

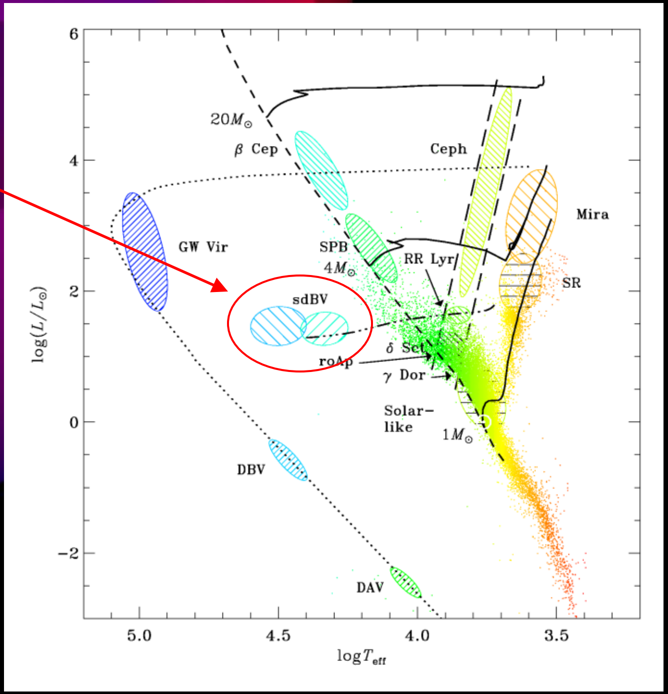
stars reside in binary systems, generally in close orbit (

Two classes of multi-periodic sdB pulsators:

~ 80 - 600 s), A ≤ 1%, p-modes (envelope)

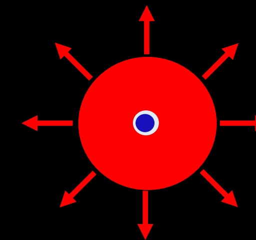
~ 45 min - 2 h), A ≤ 0.1%, g-modes (core). Space observations required !





• Single star evolution (enhanced mass loss at tip of RGB)

$0.40 - 0.43 \leq M_*/M_s \leq 0.52$ (Dorman et a



• Binary star evolution (Han et al. 2002, 2003)

elope ejection (CE), stable mass transfer by Roc

He-white dwarf mergers

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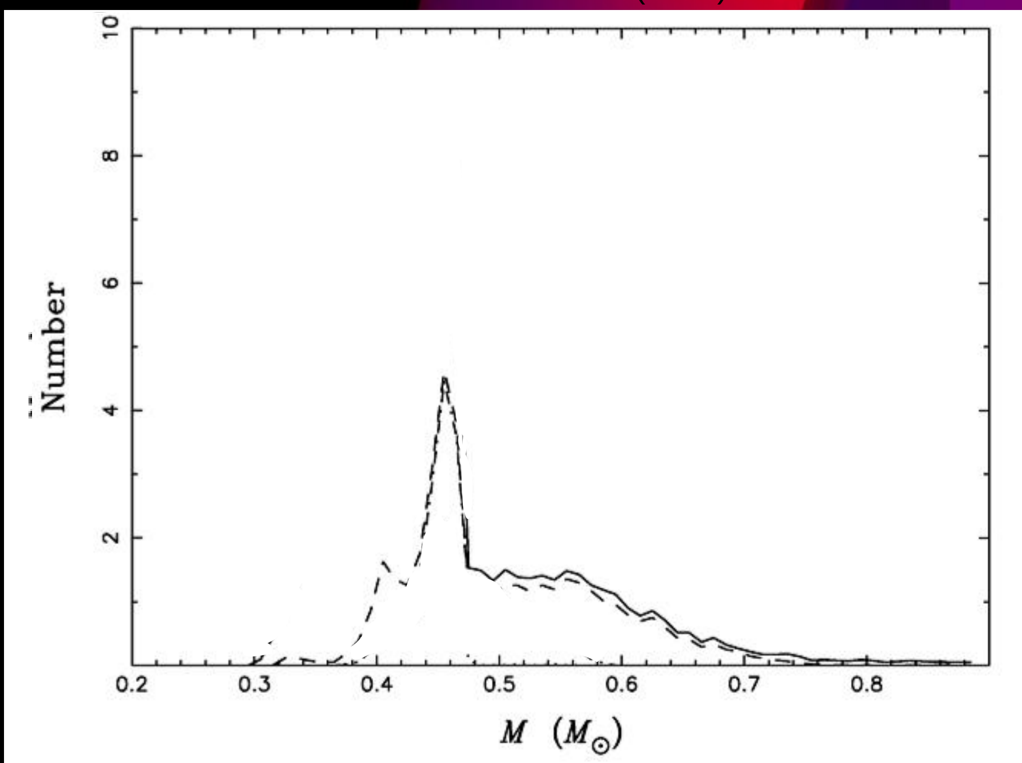


Weighted mea

for binary

(including s

$0.30 \leq M_*/M_s \leq 0.70$

peak ~ 0.46 Ms (CE, RLOF)

high masses (mergers)

Search the star model(s) whose theoretical periods best fit all the observed ones, in order to minimize

$$S^2 = \sum \frac{1}{\sigma}(P_{\rm obs} - P_{\rm th})^2$$

luding detailed envelope microscopic diffusion (no

zation codes (based on *Genetic Algorithms*) are used t
otential asteroseismic solutions

> Example: PG 1336-018, pulsating sdB + dM eclipsing binary

modeling (Vuckovic et al. 2007):

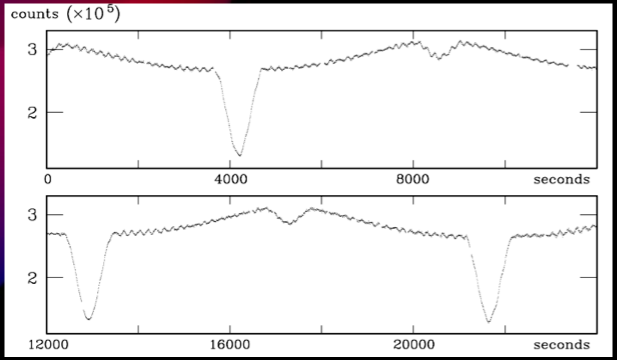
89 $\pm$ 0.005 M_s et R = 0.14 $\pm$ 0.01 R_s

II. M_{tot} = 0.466 $\pm$ 0.006 M_s et R = 0.15 $\pm$ 0.01 R_s

$\pm$ 0.007 M_s et R = 0.15 $\pm$ 0.01 R_s

arpinet et al. 2008):

M_{tot} = 0.459 $\pm$ 0.005 M_s et R = 0.151 $\pm$ 0.001 R_s



$\Rightarrow$ Our asteroseismic method is sound and free of significant systematic effects

I. The asteroseismic sample

Name	log g (cm s^{-2})	$T_{\rm eff}$ (K)	M ($M_\odot$)	log $M_{\rm env}/M$	References
PG 0014+067	5.780±0.008	33550±380	0.490±0.019	−4.31±0.22	Brassard et al. (2001)
	5.775±0.009	34130±370	0.477±0.024	−4.32±0.23	Charpinet et al. (2005a)
	5.772	34130±370	0.478	−4.13	Brassard & Fontaine (2008)
PG 1047+003	5.800±0.006	33150±200	0.490±0.014	−3.72±0.11	Charpinet et al. (2003)
PG 1219+534	5.807±0.006	33600±370	0.457±0.012	−4.25±0.15	Charpinet et al. (2005b)
Feige 48	5.437±0.006	29580±370	0.460±0.008	−2.97±0.09	Charpinet et al. (2005c)
	5.462±0.006	29580±370	0.519±0.009	−2.52±0.06	Van Grootel et al. (2008a)
EC 05217−3914	5.730	32000	0.490	−3.00	Billères & Fontaine (2005)
PG 1325+101	5.811±0.004	35050±220	0.499±0.011	−4.18±0.10	Charpinet et al. (2006a)
PG 0048+092	5.711±0.010	33300±1700	0.447±0.027	−4.92±0.20	Charpinet et al. (2006b)
EC 20117−4014	5.856±0.008	34800±2000	0.540±0.040	−4.17±0.08	Randall et al. (2006b)
PG 0911+456	5.777±0.002	31940±220	0.390±0.010	−4.69±0.07	Randall et al. (2007)
BAL 090100001	5.383±0.004	28000±1200	0.432±0.015	−4.89±0.14	Van Grootel et al. (2008b)
PG 1336−018	5.739±0.002	32780±200	0.459±0.005	−4.54±0.07	Charpinet et al. (2008)
PG 1605+072	5.248	32300±300	0.707	−5.78	van Spaandonk et al. (2008)
	5.217	32300±300	0.561	−6.22	
	5.226±0.004	32300±300	0.528±0.002	−5.88±0.04	Van Grootel (2008)
	5.276	32630±600	0.731	−2.83	Van Grootel et al. (2010a)
	5.278	32630±600	0.769	−2.71	
EC 09582−1137	5.788±0.004	34805±230	0.485±0.011	−4.39±0.10	Randall et al. (2009)
KPD 1943+4058	5.520±0.030	27730±270	0.496±0.002	−2.55±0.07	Van Grootel et al. (2010b)
KPD 0629−0016	5.450±0.034	26485±195	0.471±0.002	−2.42±0.07	Van Grootel et al. (2010c)
KIC02697388	5.489±0.033	25395±225	0.463±0.009	−2.30±0.05	Charpinet et al. (2011)
	5.499±0.049	25395±225	0.452±0.012	−2.35±0.05	

15 sdB stars modeled by asteroseismology

II. The extended sample
(sdB + WD or dM star)

Name	log g (cm s^{-2})	$T_{\rm eff}$ (K)	M_1 ($M_\odot$)	Nature	Eclipses	References
KPD 0422+5421	5.565±0.009	25000±1500	0.511±0.049	sdB+WD	yes	Orosz & Wade (1999)
PG 1241−084	5.63±0.03	28490±210	0.48±0.09	sdB+dM	yes	Wood & Saffer (1999)
	5.60±0.12	28490±210	0.485±0.013			Lee et al. (2009)
HS 0705+6700	5.40±0.10	28800±900	0.48	sdB+dM	yes	Drechsel et al. (2001)
HS 2333+3927	5.70±0.10	36500±1000	0.38	sdB+dM	no	Heber et al. (2005)
NSVS 14256825	5.50±0.02	35000±5000	0.46	sdB+dM	yes	Wils et al. (2007)
PG 1336−018	5.74±0.05	31300±300	0.389±0.005	sdB+dM	yes	Vuckovic et al. (2007)
	5.77±0.06	31300±300	0.466±0.006			
	5.79±0.07	31300±300	0.530±0.007			
2M 1533+3759	5.57±0.07	29230±125	0.376±0.055	sdB+dM	yes	For et al. (2010)
2M 1938+4603	5.425±0.009	29565±105	0.48±0.03	sdB+dM	yes	Østensen et al. (2010)
KPD 1946+4340	5.452±0.006	34500±400	0.47±0.03	sdB+WD	yes	Bloemen et al. (2011)

…deling + spectroscopy ⇒ mass of the sdB …

Need uncertainties to build a mass distribution

⇒ 5 sdB stars retained in this subsample

Extended sample: … = 20 sdB stars with ac…

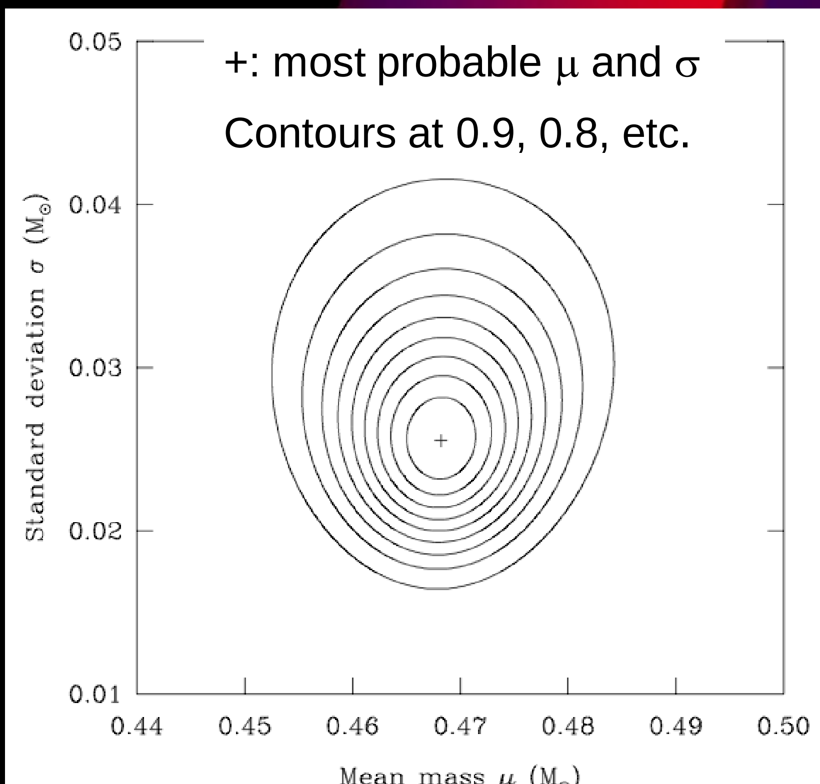
…arently) si…

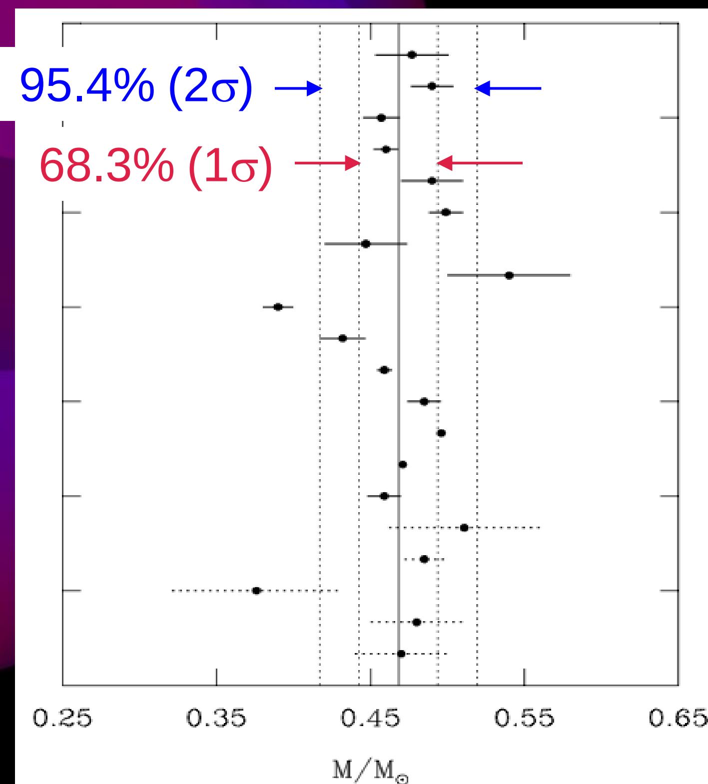
I. Assumption of a normal distribution

$$L(\mu,\sigma) = \prod_{i=1}^{N} [2\pi(\sigma^2+\sigma_i^2)]^{-1/2} \exp\{-\frac{(m_i-\mu)^2}{2(\sigma^2+\sigma_i^2)}\}$$

...ded sample: $\mu = 0.468$ Ms and $\sigma = 0.026$ ...

...eroseismic sample: $\mu = 0.467$ Ms and $\sigma = 0.0$...



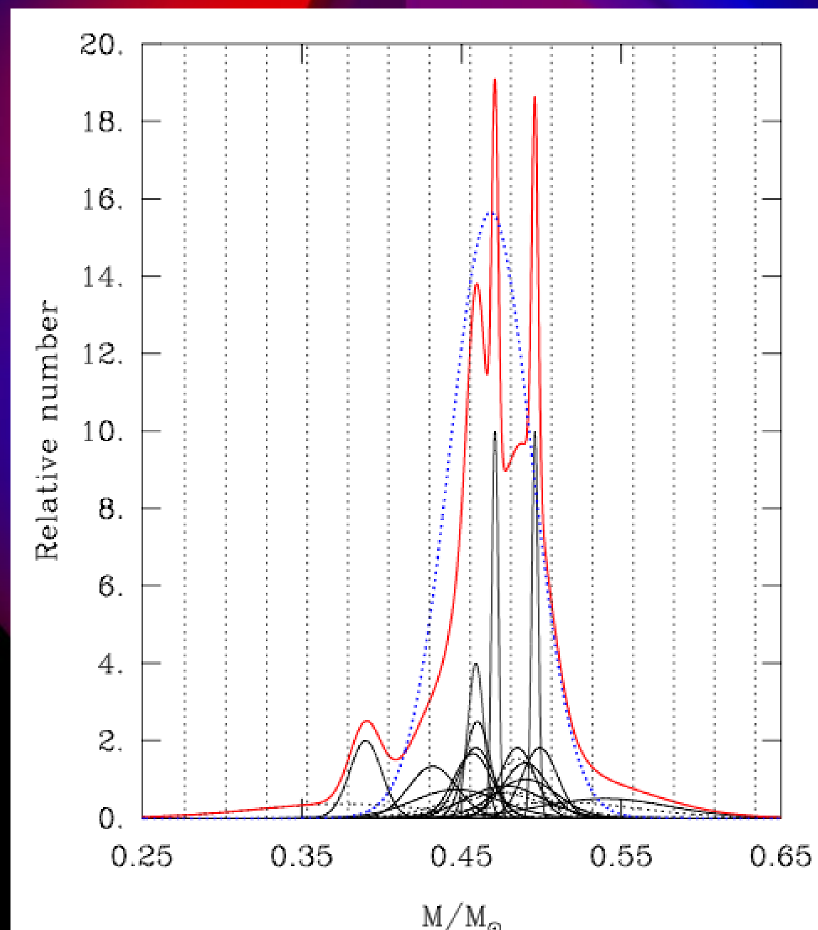


II. Model-free distribution

...sumed to obey normal di...

Red curve: ... of all sdBs (mass with uncertaintie...

Blue curve: ...nal distribution (μ = 0.468 Ms and σ = 0.0...



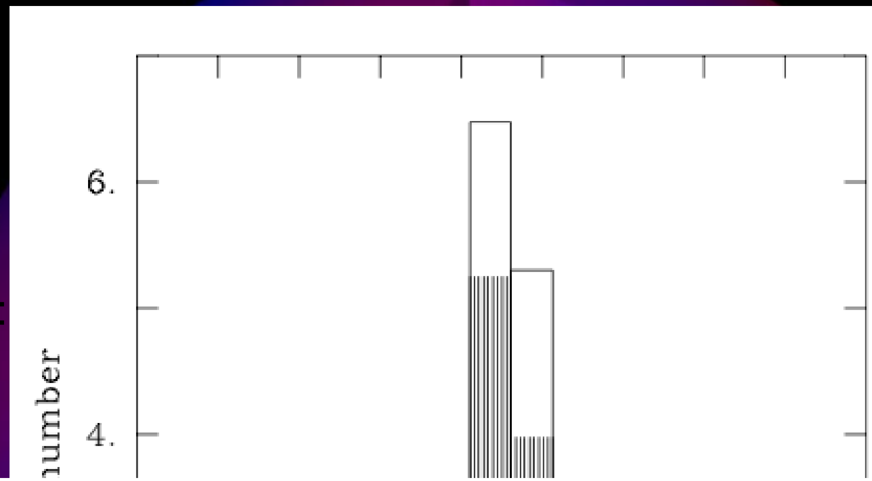
m of an histogram

0.469 Ms

0.471 Ms

ars:

0.436-0.501 Ms



(

Me 0.470 Ms

Med 0.471 Ms

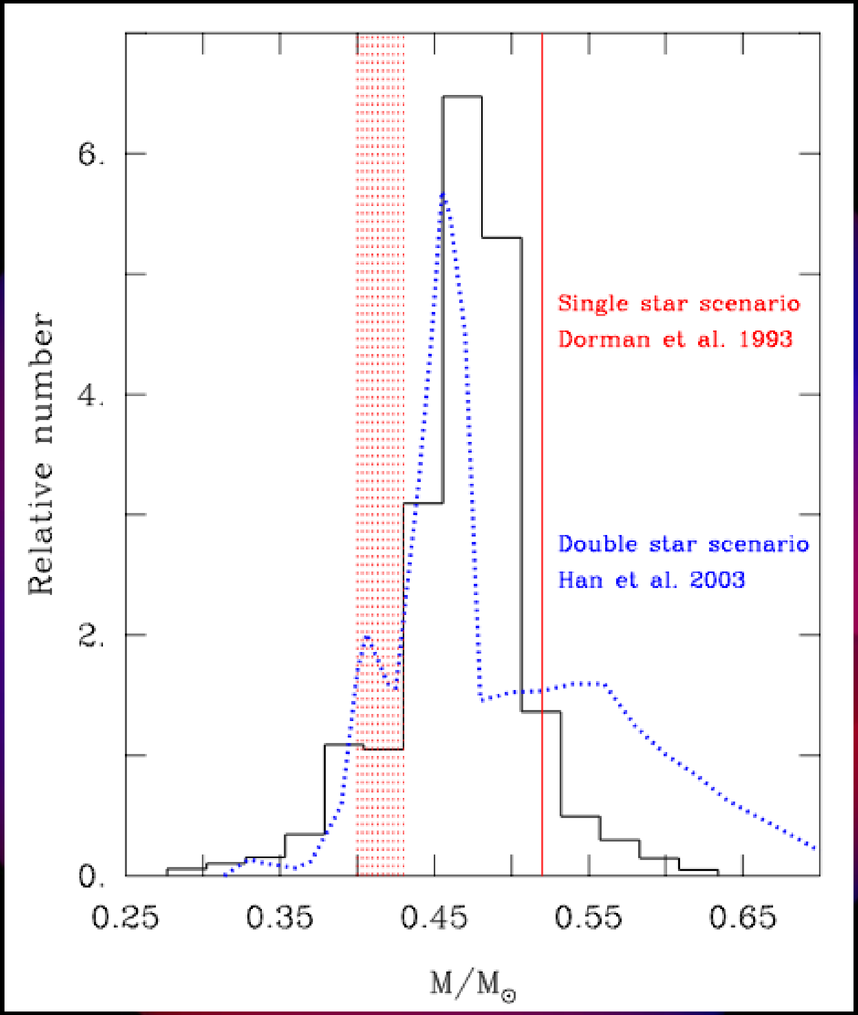
Rang

0.441-0.499 Ms

Sample	Mean mass ($M_\odot$)	Median mass ($M_\odot$)	Range of mass (68.3%; $M_\odot$)
extended (20 stars)	0.469	0.471	0.436–0.501
15 pulsators	0.470	0.471	0.441–0.499
5 binaries (orbits)	0.464	0.476	0.411–0.510
9 binaries (total)	0.470	0.466	0.435–0.515
11 singles	0.468	0.473	0.437–0.498

No detectable significant differences between distributions

(especially between singles and binaries)



Empirical distribution agrees well with expectations of stellar evolution theory...but still small-number statistics !

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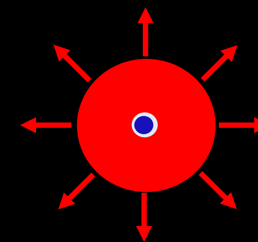
0.40 - 0.43 ≤ M_*/M_s ≤ 0.52 (Dorman et a



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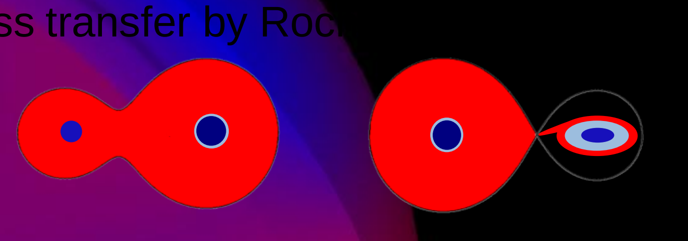

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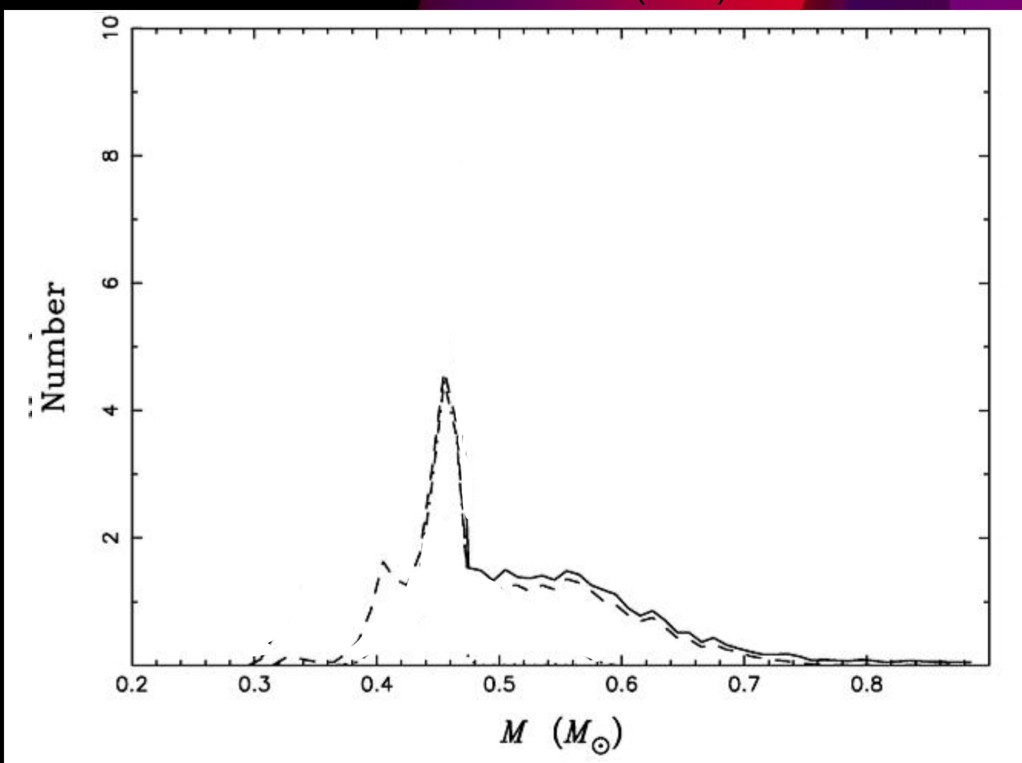

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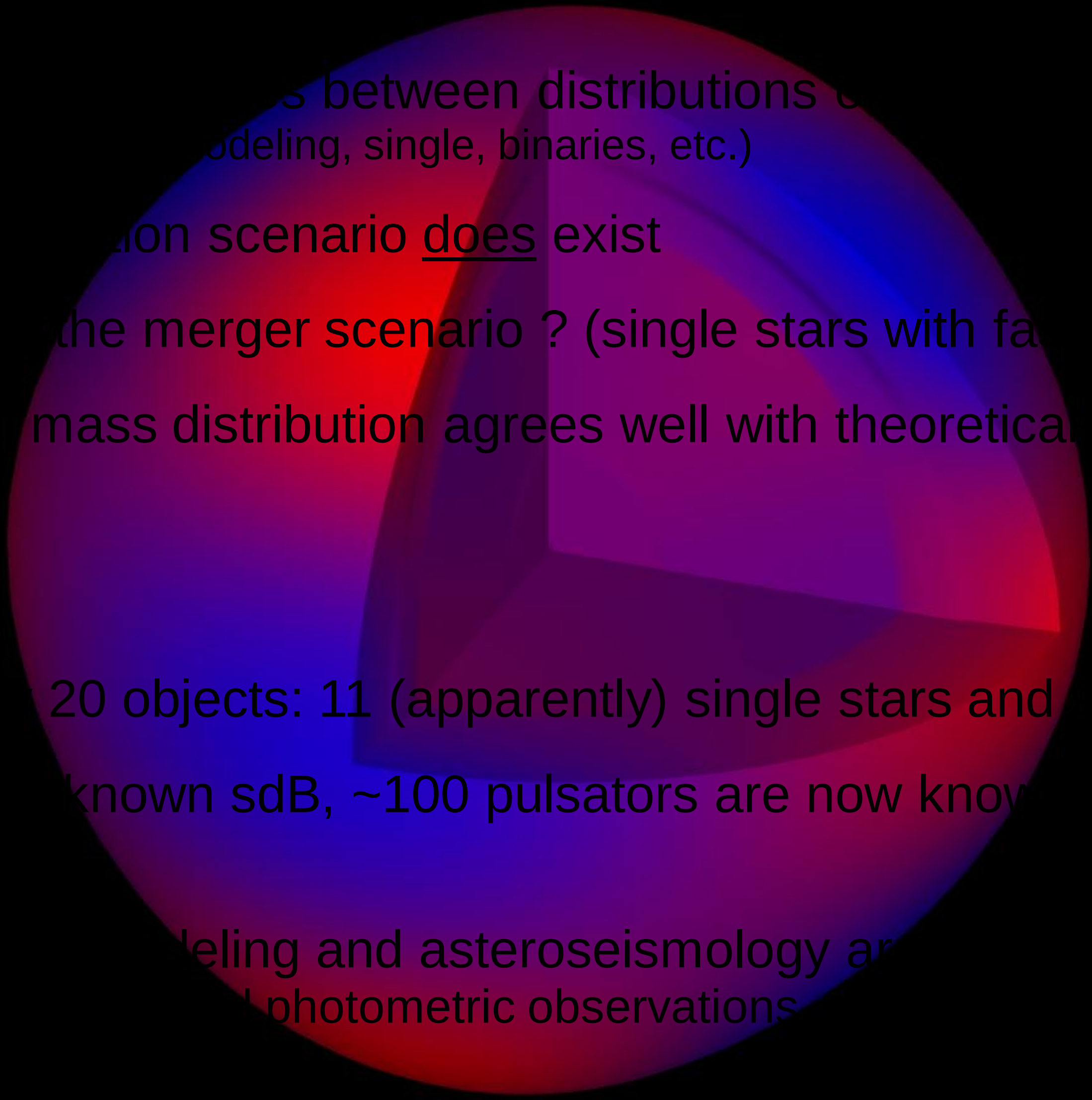

…s between distributions o…

…odeling, single, binaries, etc.)

…tion scenario <u>does</u> exist

…the merger scenario ? (single stars with fa…

…mass distribution agrees well with theoretical…

But:

… 20 objects: 11 (apparently) single stars and …

…known sdB, ~100 pulsators are now know…

…leling and asteroseismology ar…

…l photometric observations…