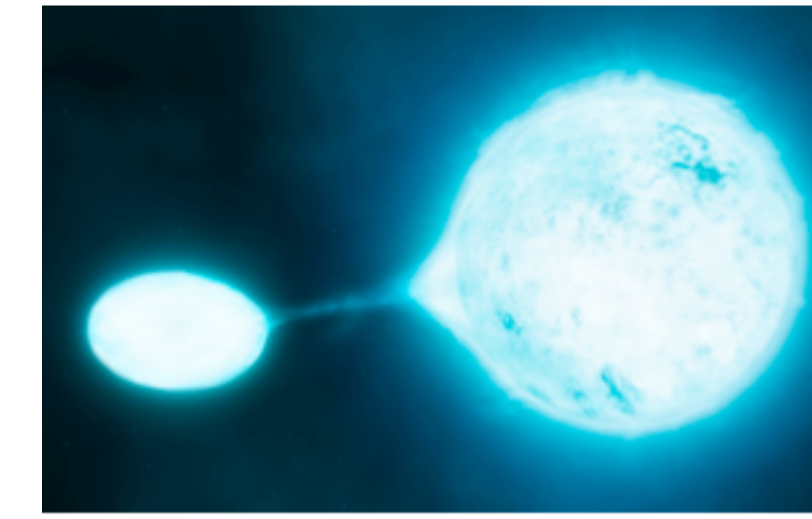
R Coronae Borealis
Best candidates for Double Degenerate merger product in the intermediate mass range.

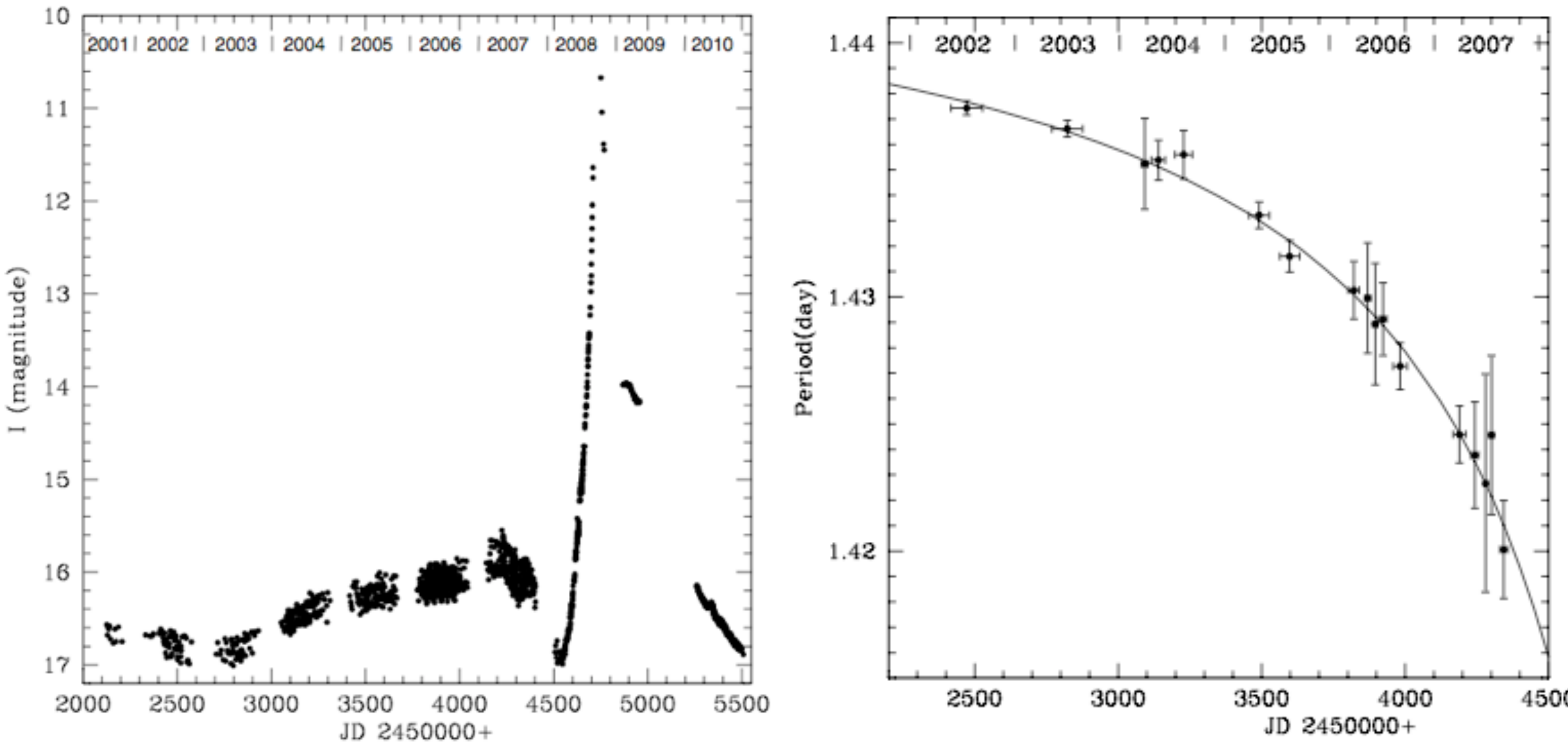
Patrick Tisserand (IAP)

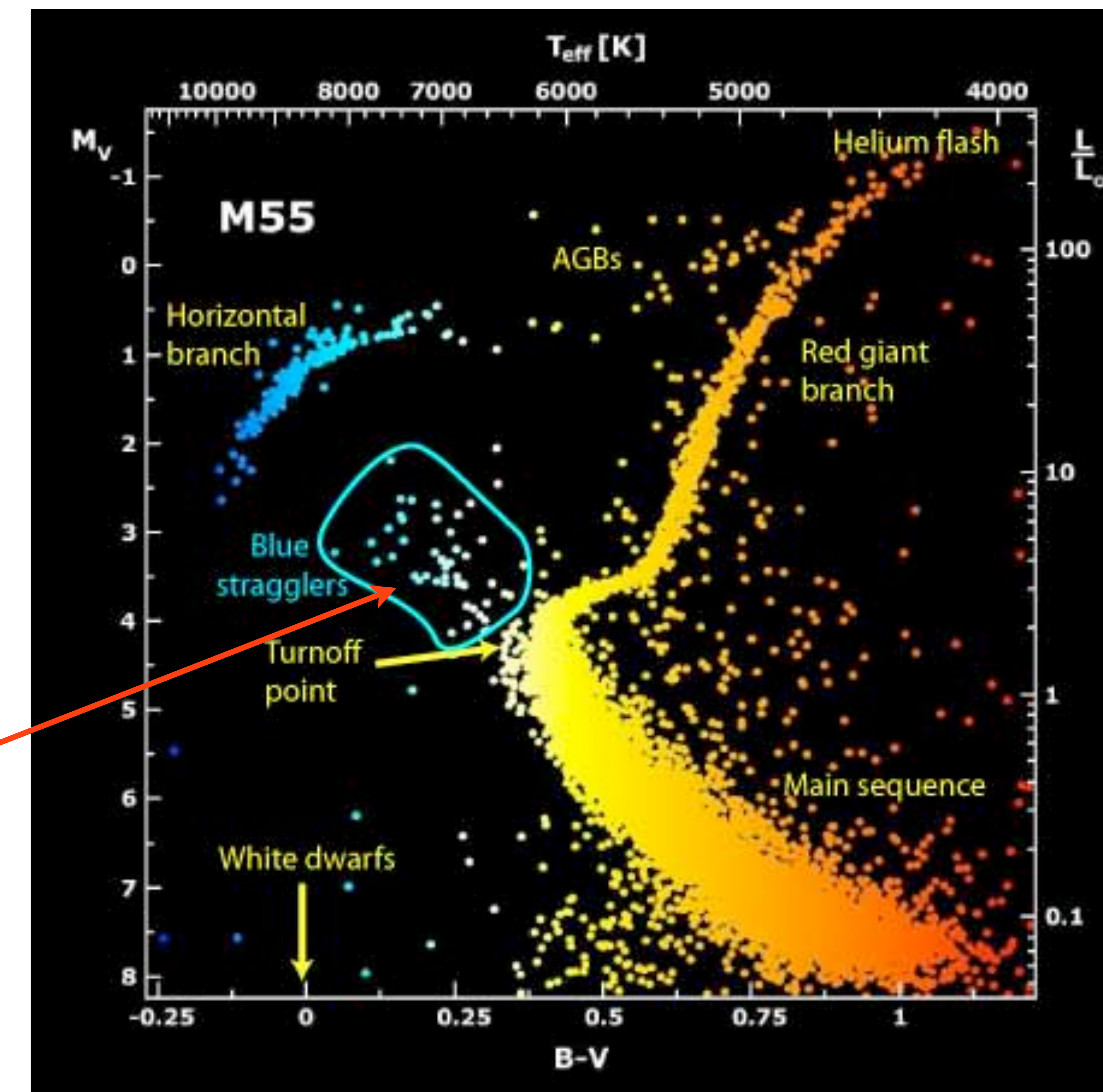
Clayton, G. ; (Uni. Baton rouge, USA) , Welch, D. (Uni. Tornoto, Can), Marquette, J.B. (IAP), Wood, P. (ANU, Aus.), Ruiter (ANU, Aus.) , Garcia-Hernandez, A. (Esp), Montiel, E. (Uni. Baton rouge, USA), Geballe, T. (Gemini)

Merger exist !

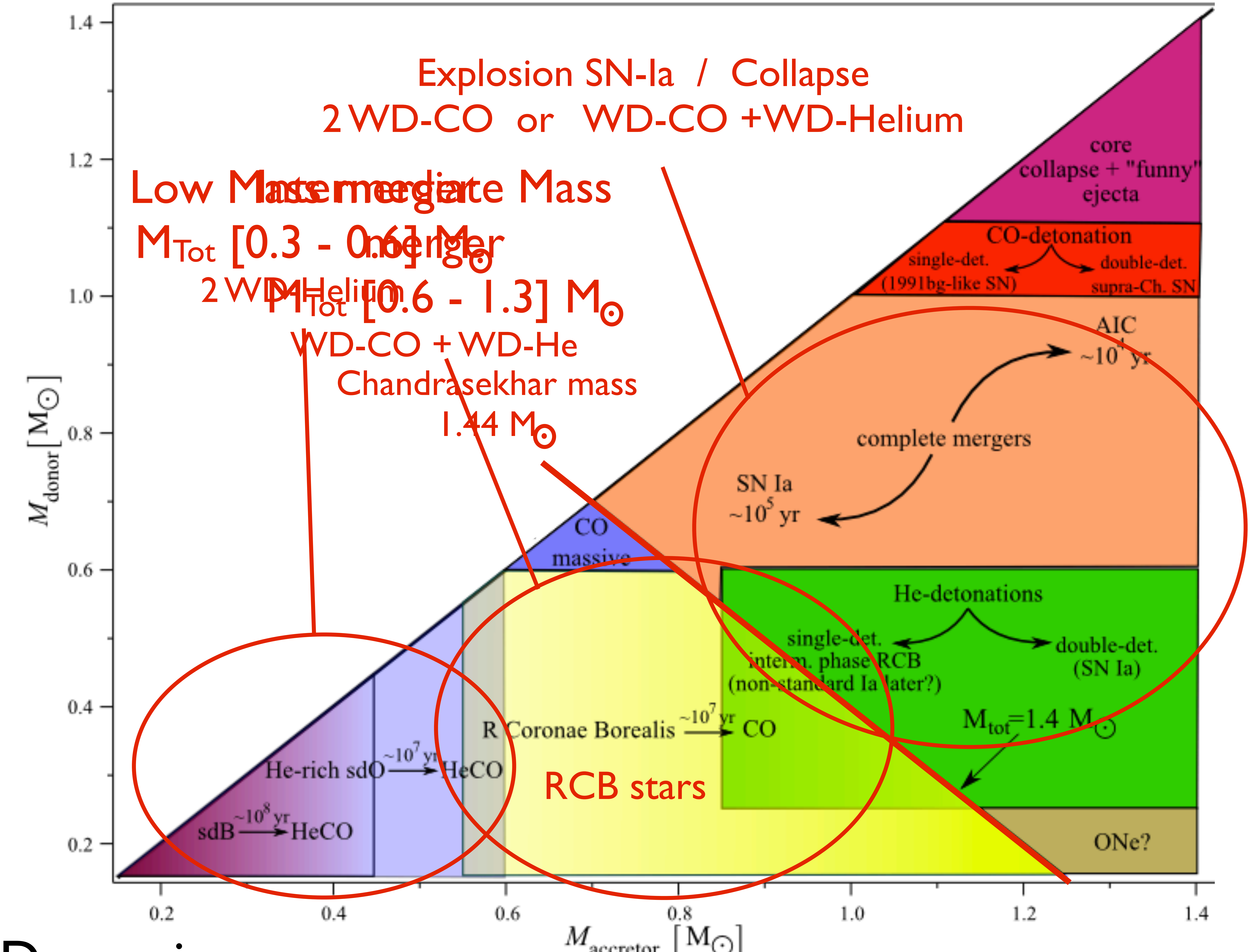


V1309 Sco *Tylenda et al., 2011*
OGLE discovery





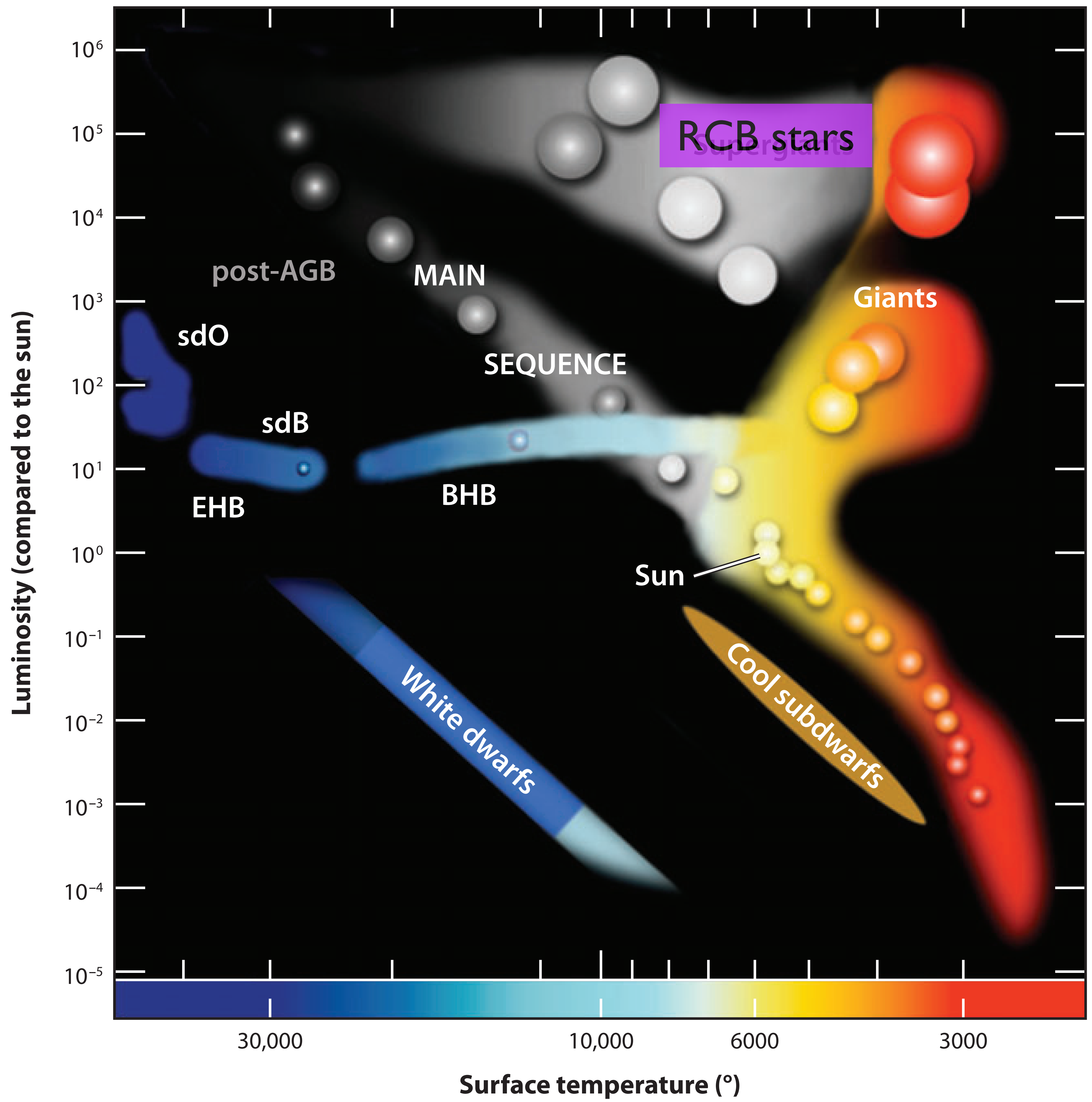
Blue stragglers
[No spectroscopic companion]



2 WD merging

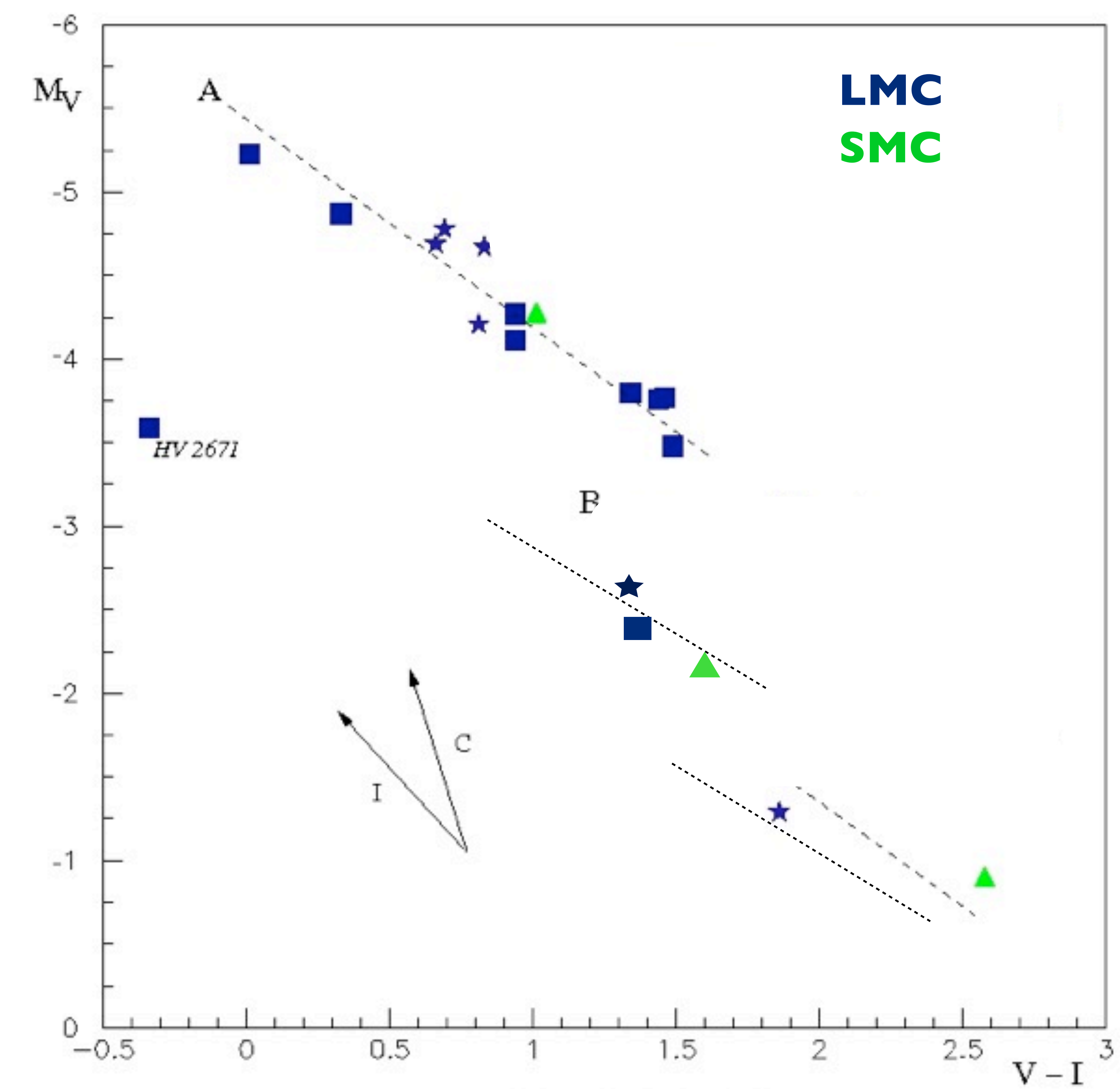
Mariuz Dan (Bremen, phd student)

Rare objects but very bright...



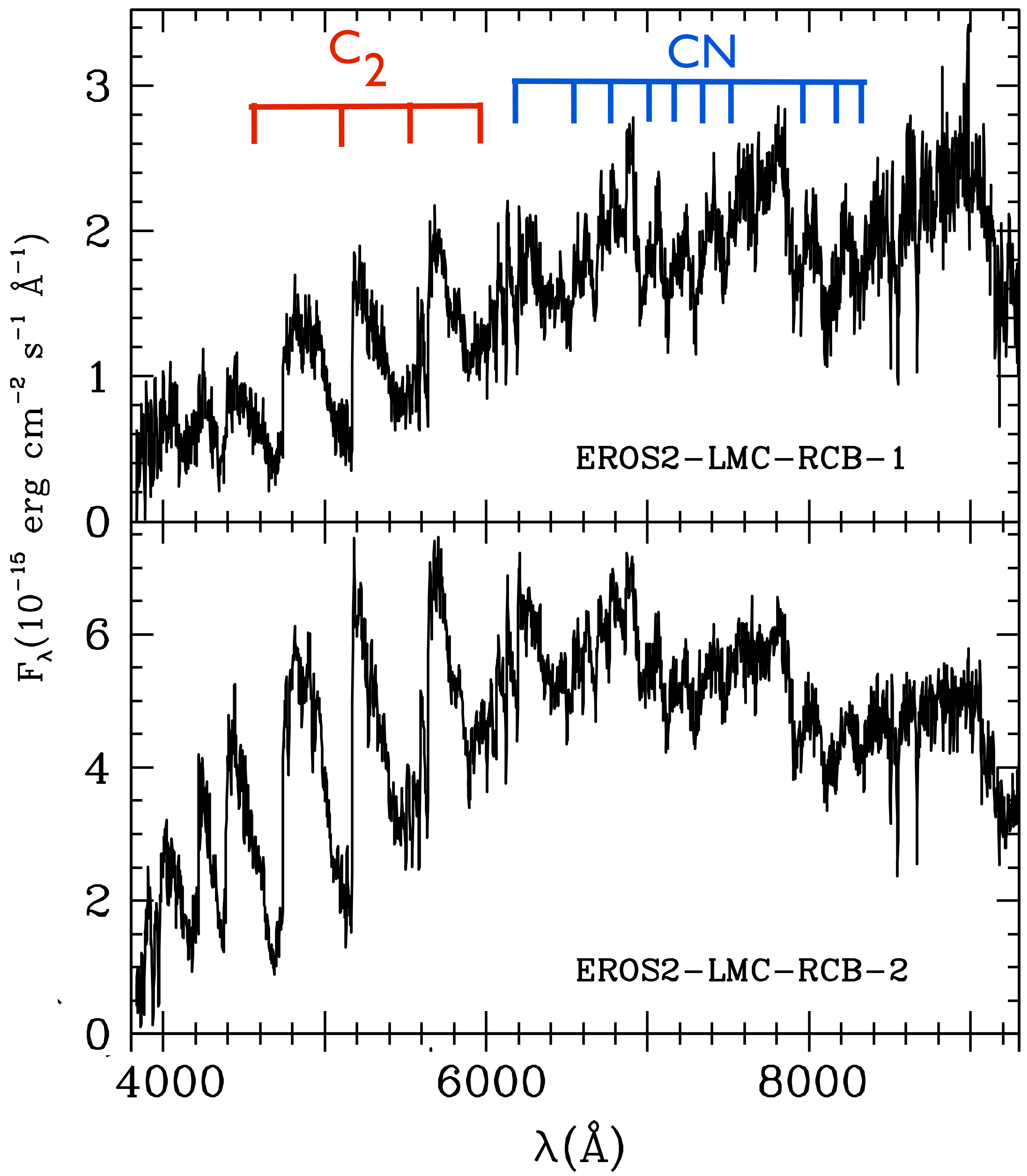
Effective Temperature
8000 to 4000 K
Spectral type: F to K

$-5.2 \leq M_V \leq -3.4$



Tisserand et al., 2009

<u>Atmosphere composition</u>: H-deficient, 99% Helium, enriched in C



Main low res. spectral characteristic :
No Halpha , CH features
low 13C/12C ratio
low CN / C2 ratio.

They display an extraordinary mixture of atomic species in ratios very different to those likely to have been established when the star was formed.

<u>Anomalies</u> include large enrichments of N, O, F, Ne and P, detections s-process elements, over-abundance in Si and S, together with a large range in iron abundance (Jeffery 1996; Rao & Lambert 1996; Pandey et al. 2006)

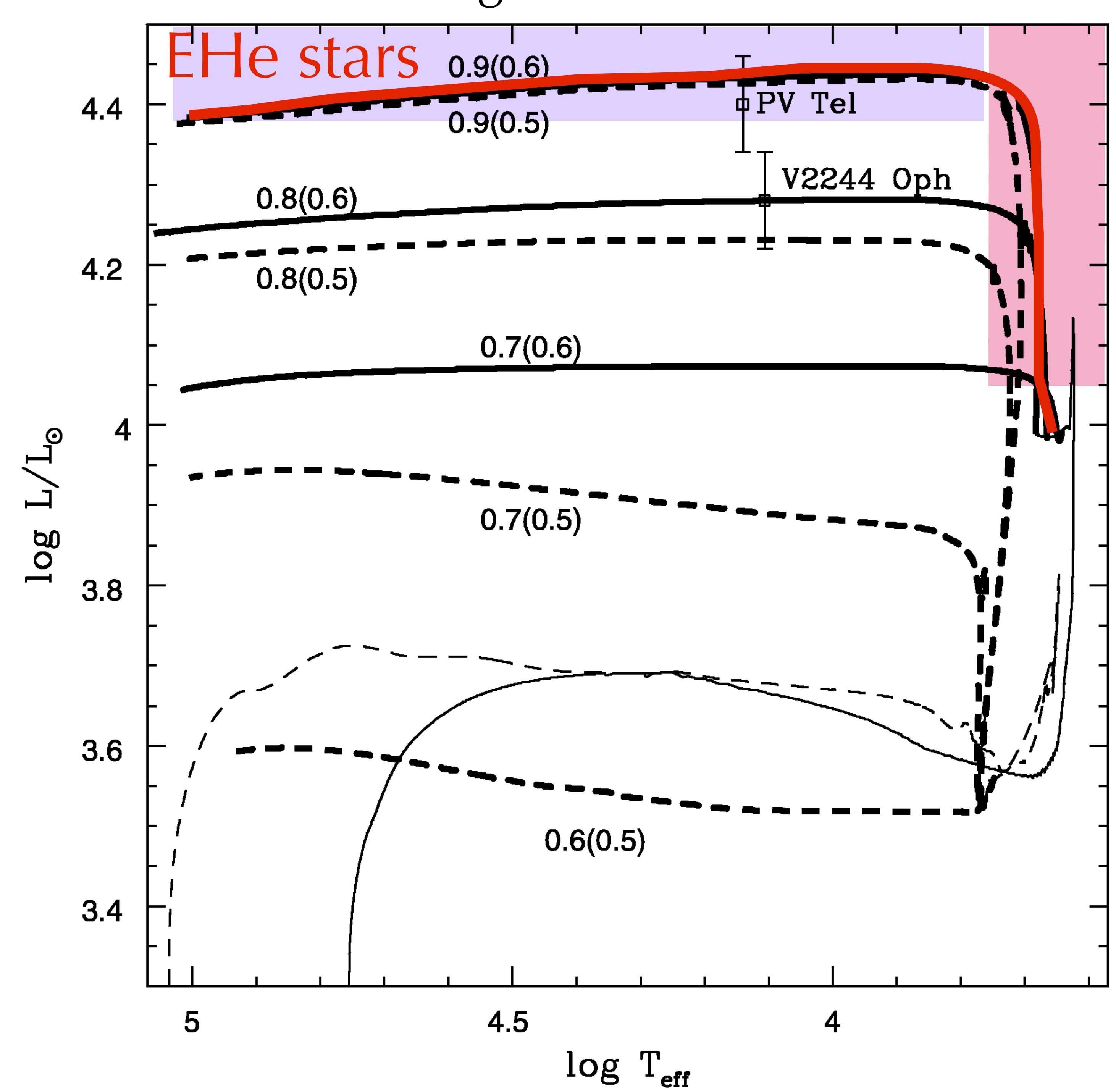
→ RCBs correspond either to a brief phase of stellar evolution or an uncommon evolutionary path.

$^{16}O/^{18}O$ ~ 1 observed in RCB stars
but this ratio ~ 500 in the sun.
(Clayton, 2005 & 2007, Garcia-Hernandez, 2010)

Expected numbers

	Total Mass	Rate (Ruiter, 2009)
WD-He + WD-He => sdB/O stars ?	~0.5M⊙	~0.8 /100 yrs
WD-He + WD-CO => RCBs ?	~0.9M⊙	~0.5 /100 yrs
WD-CO + WD-CO => SnIa, WR?, NS ?	~1.2M⊙	~0.9 /100 yrs (0.3 for Mass >Mch)

WD-He + WD-CO merger evolution :



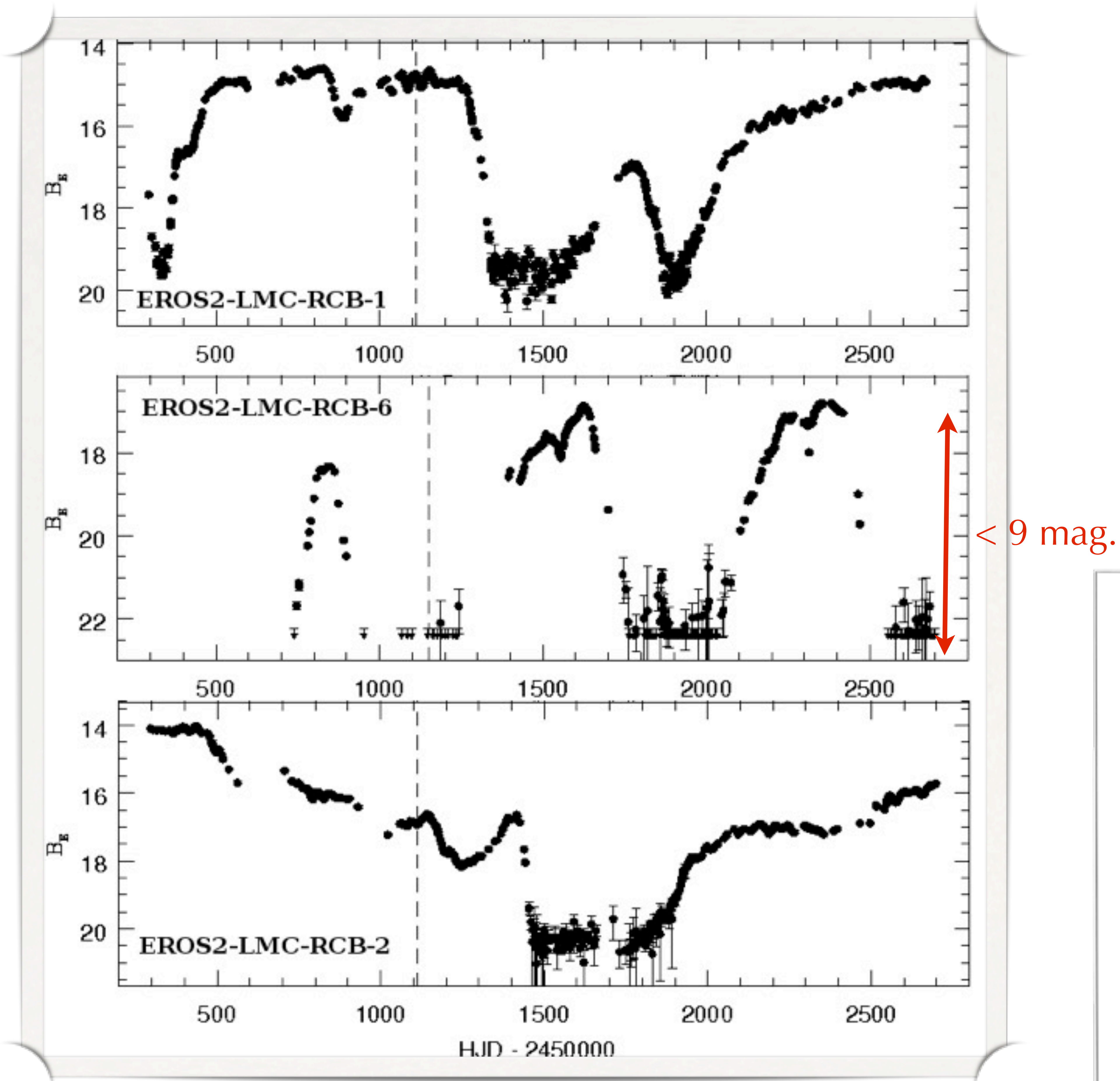
Saio & Jeffery, MNRAS 2002

RCB phase
~10^5 yrs

We expect ~500 RCBs in our Galaxy
(between 300 to 2000 depending on model)

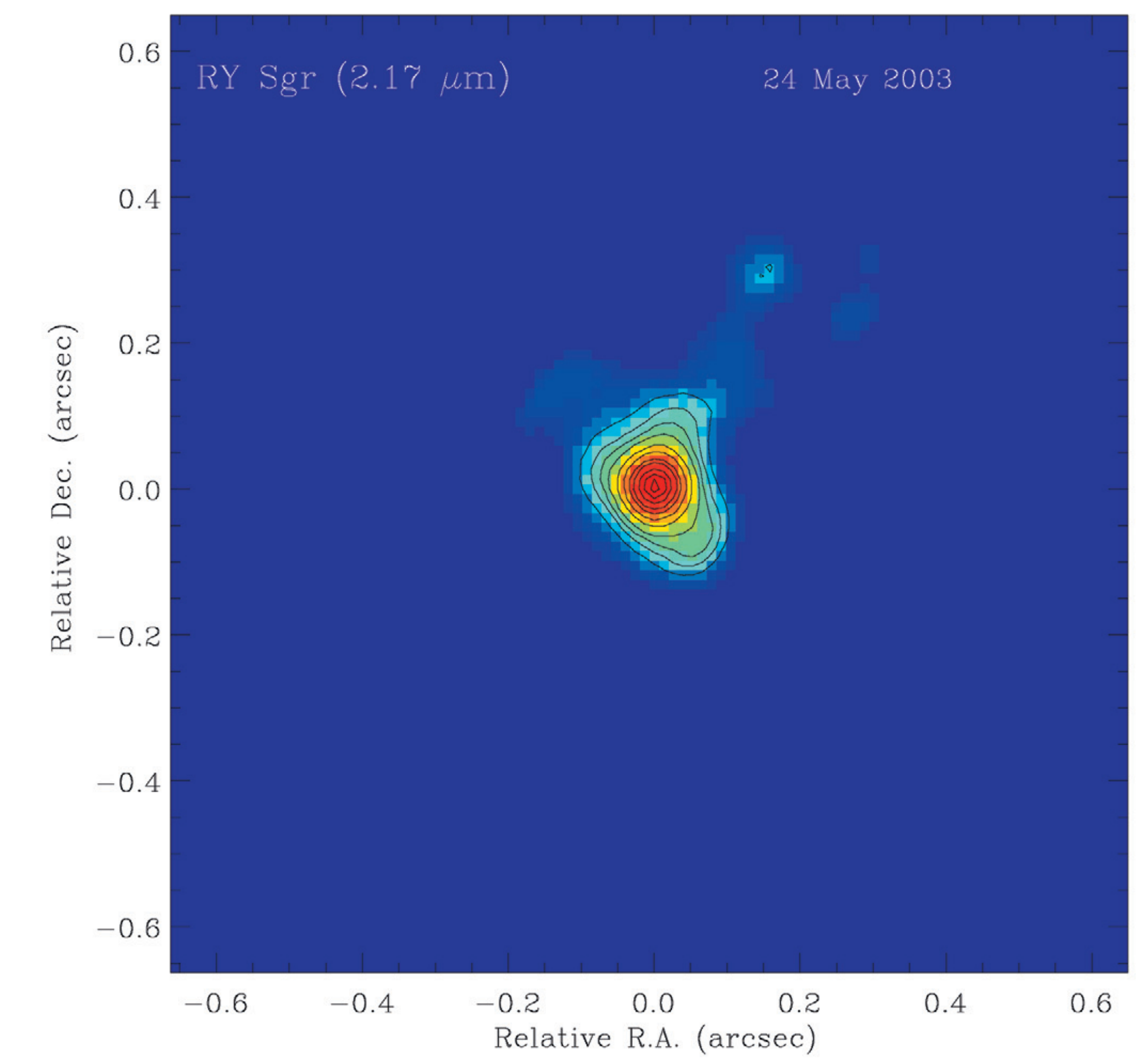
The good estimation of the total number of Galactic RCBs will give strong constraint on population synthesis model

Dust formation

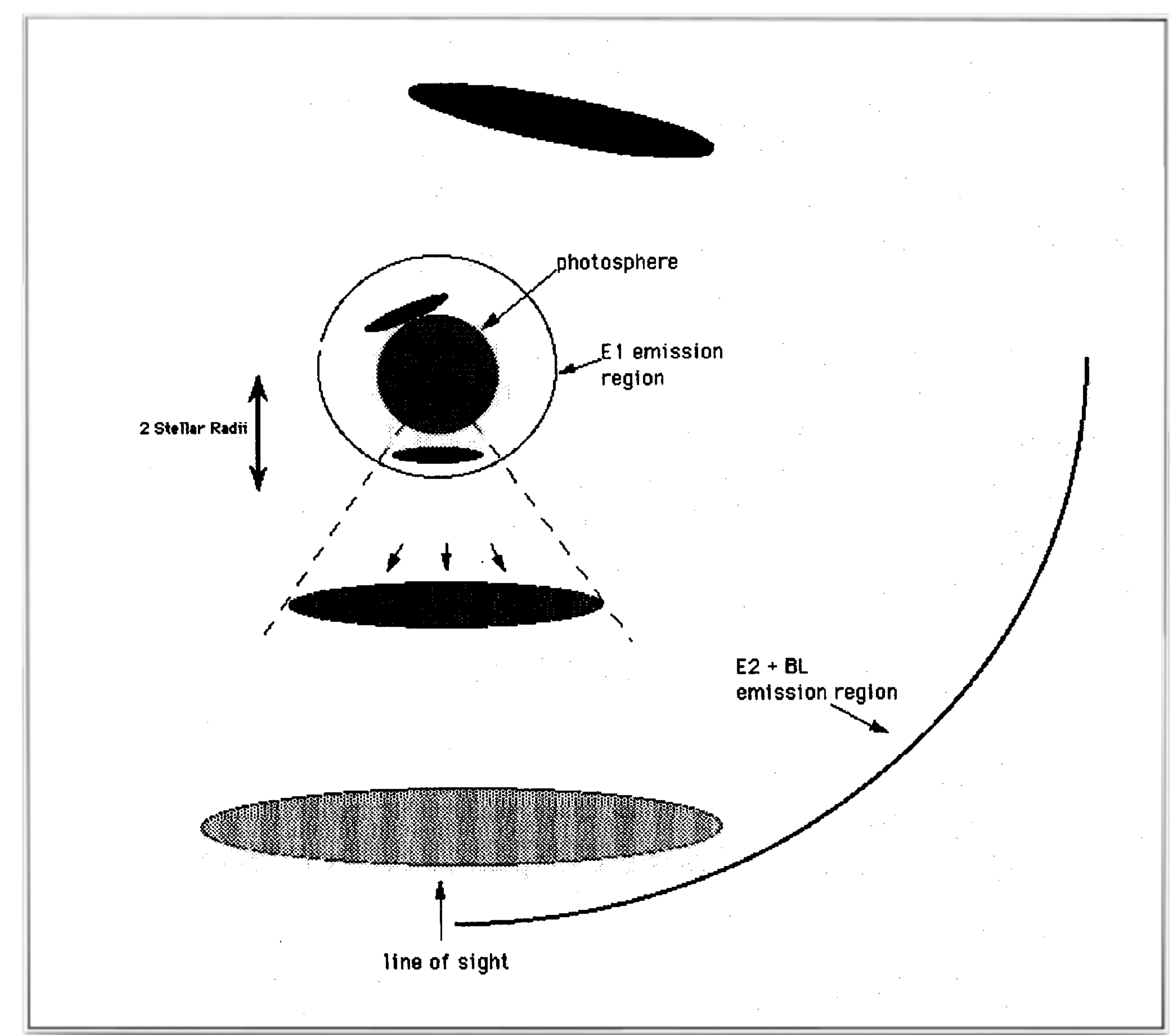


Luminosity declines ~ 0.1 - 0.03 mag/day

Production rate : ~10^{-5} $M_{\odot}$ /year



Adaptive optic, De Laverny, 2004

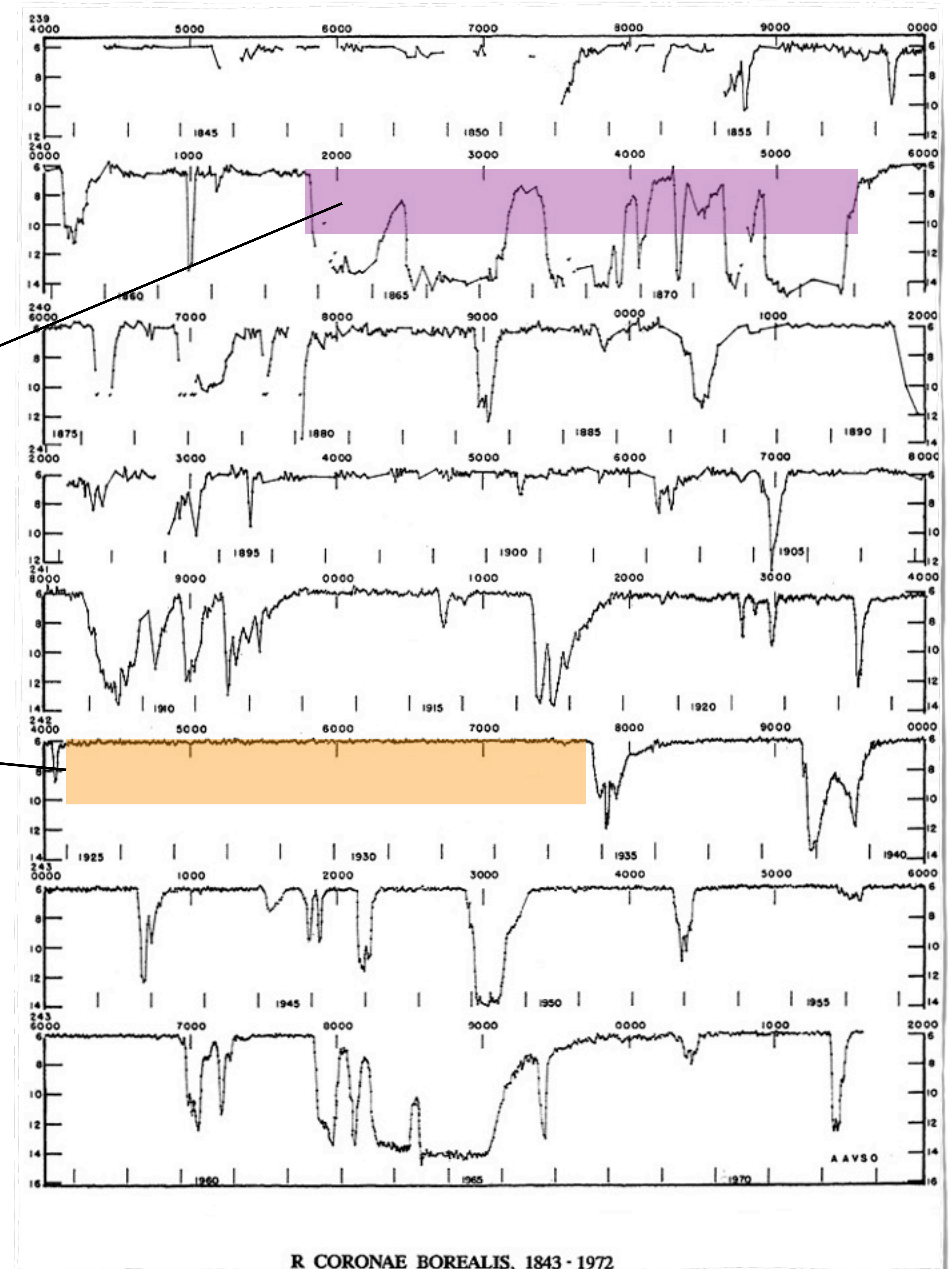


Clayton, 1996

R CrB light curve since 1843

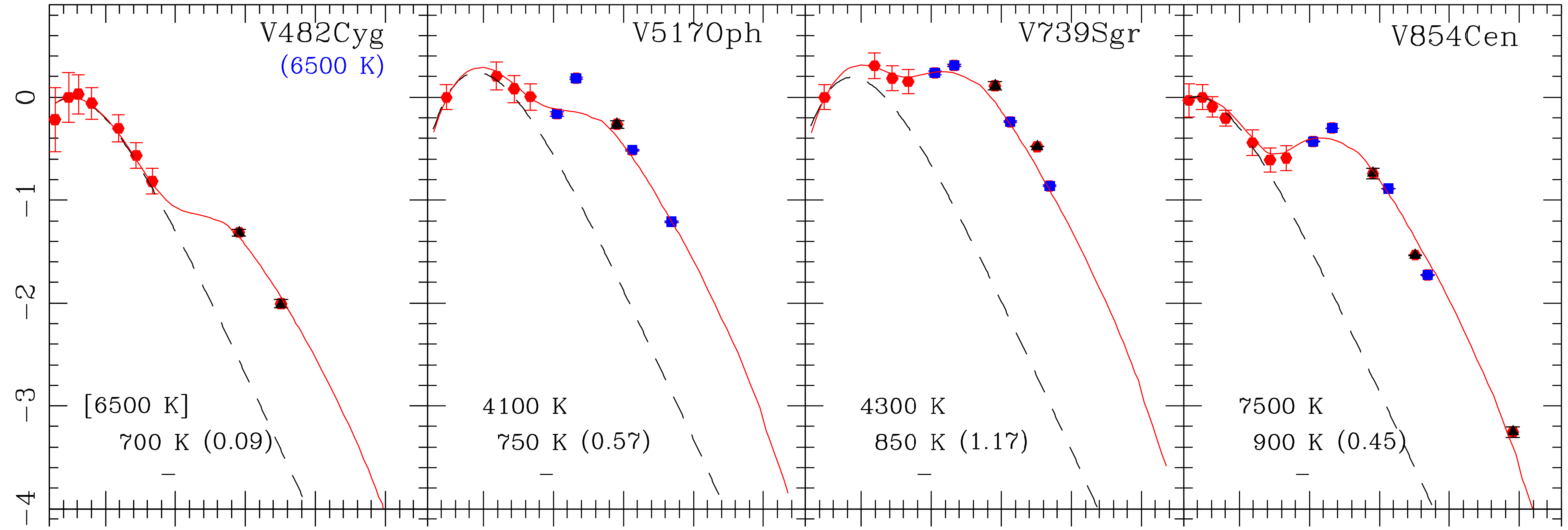
Period of strong activity

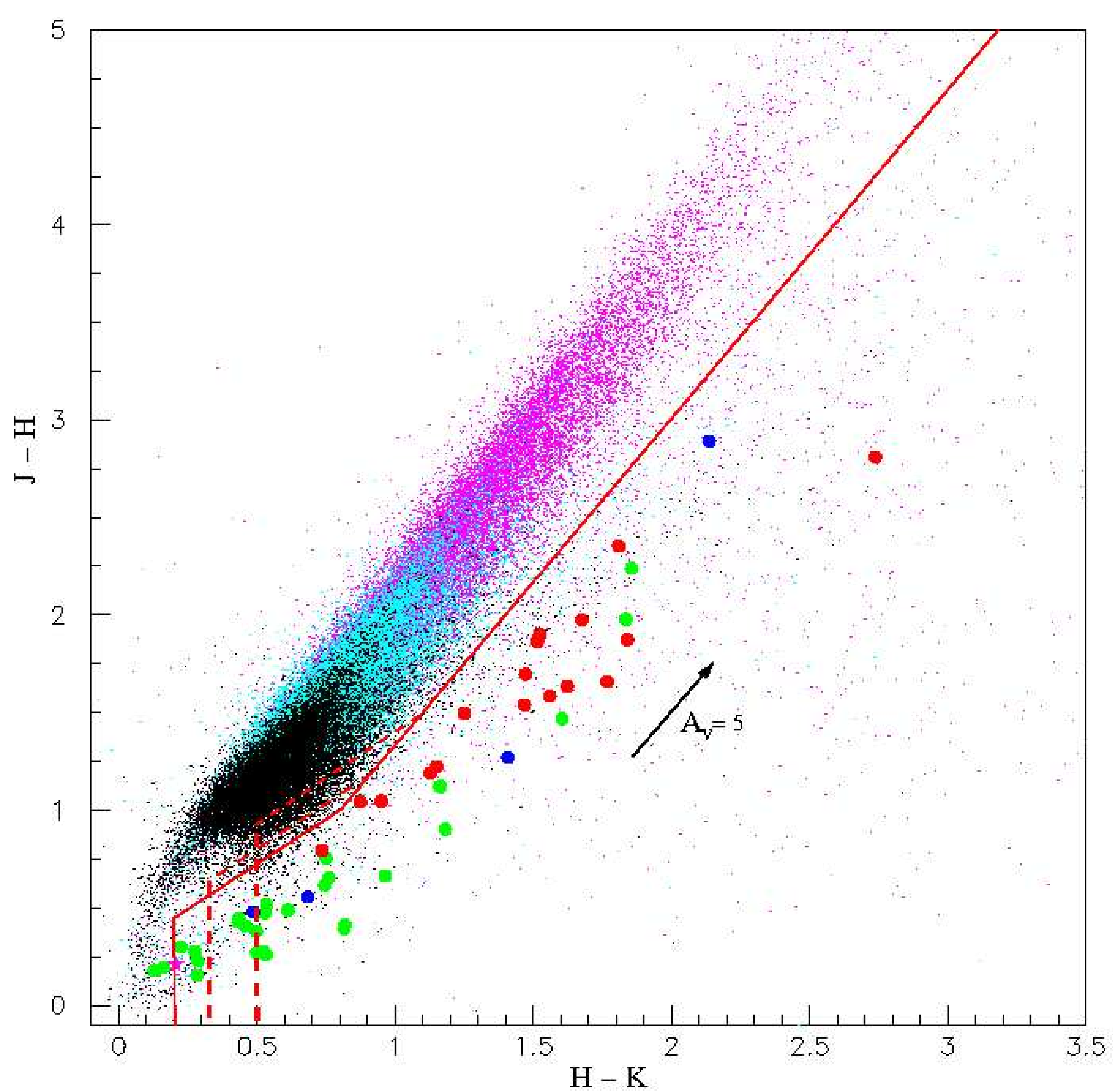
Remained bright for ~10 yrs continously.

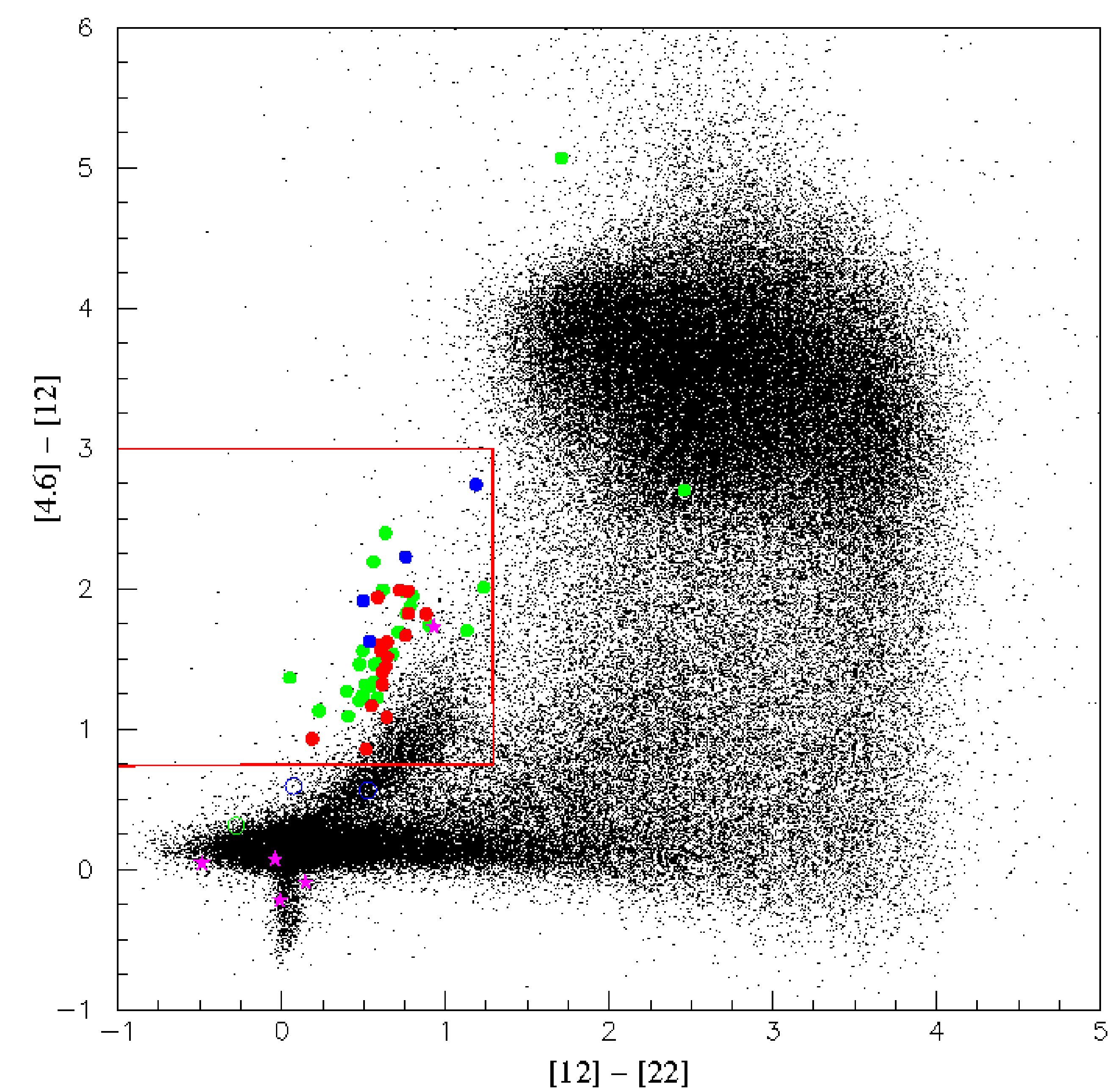


Search in the WISE all sky catalogue

Warm shell
T_{eff} ~ 350 - 1000 K



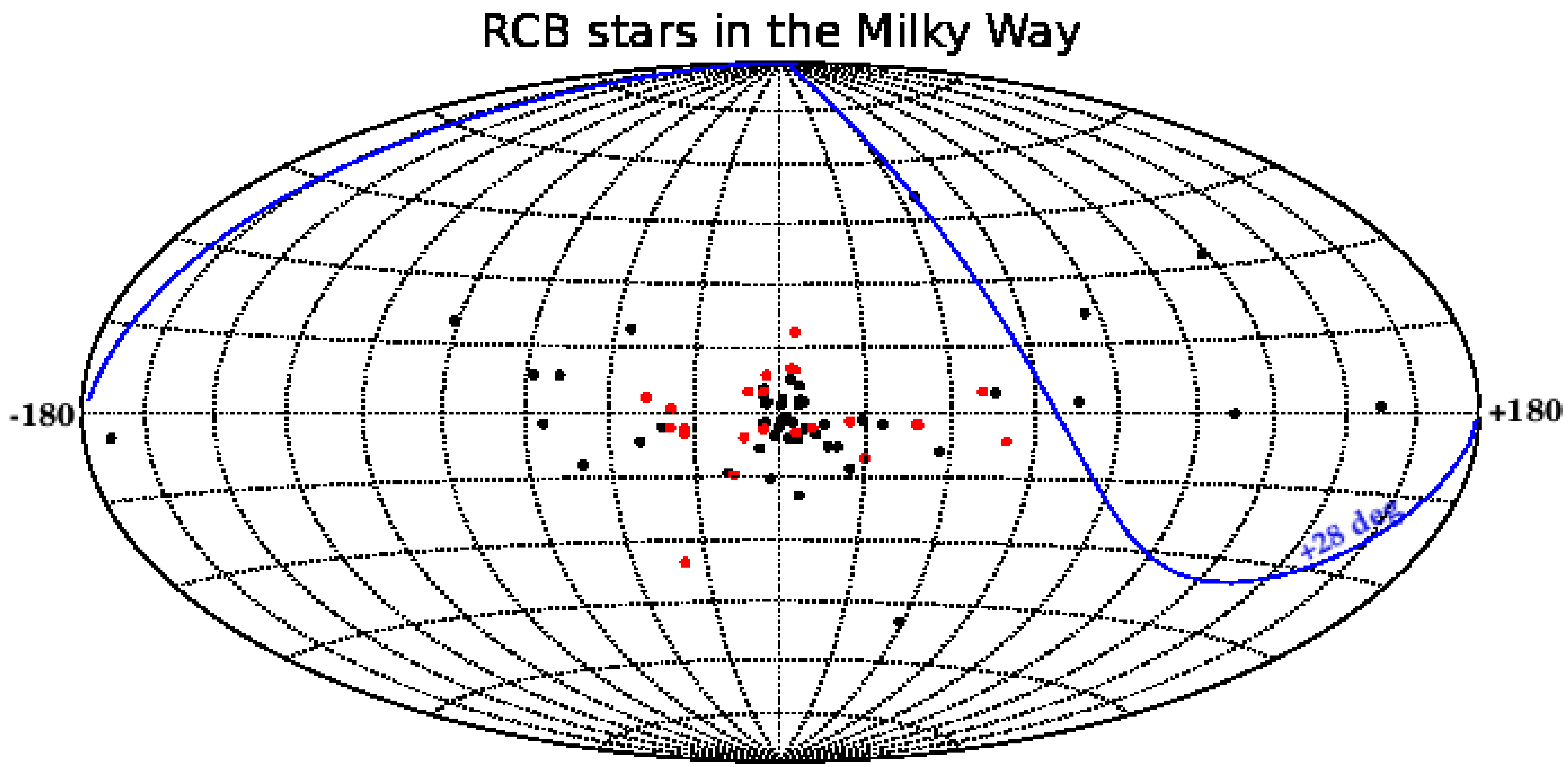




Catalogue of 1600 candidates was produced
with a detection efficiency of 77%

Tisserand P., 2012, A&A 539, A51

Bulge distribution:



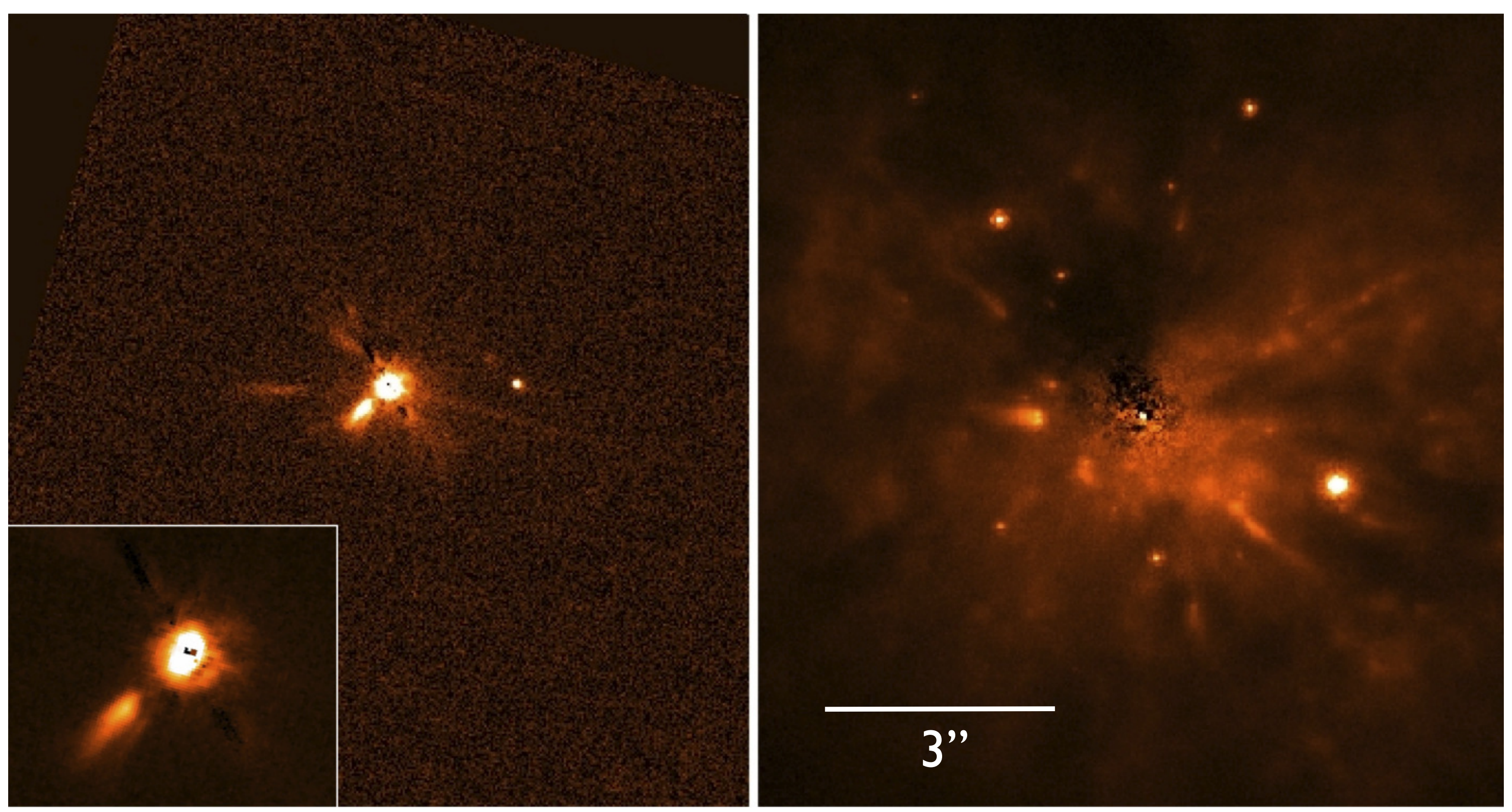
76 RCBs are now known in our Galaxy
22 in the Magellanic Clouds.

Search in the ASAS survey Database:
Tisserand P., et al. (2012)
arXiv:1211.2475 (accepted in A&A)

Search up to 50 kpc / sun

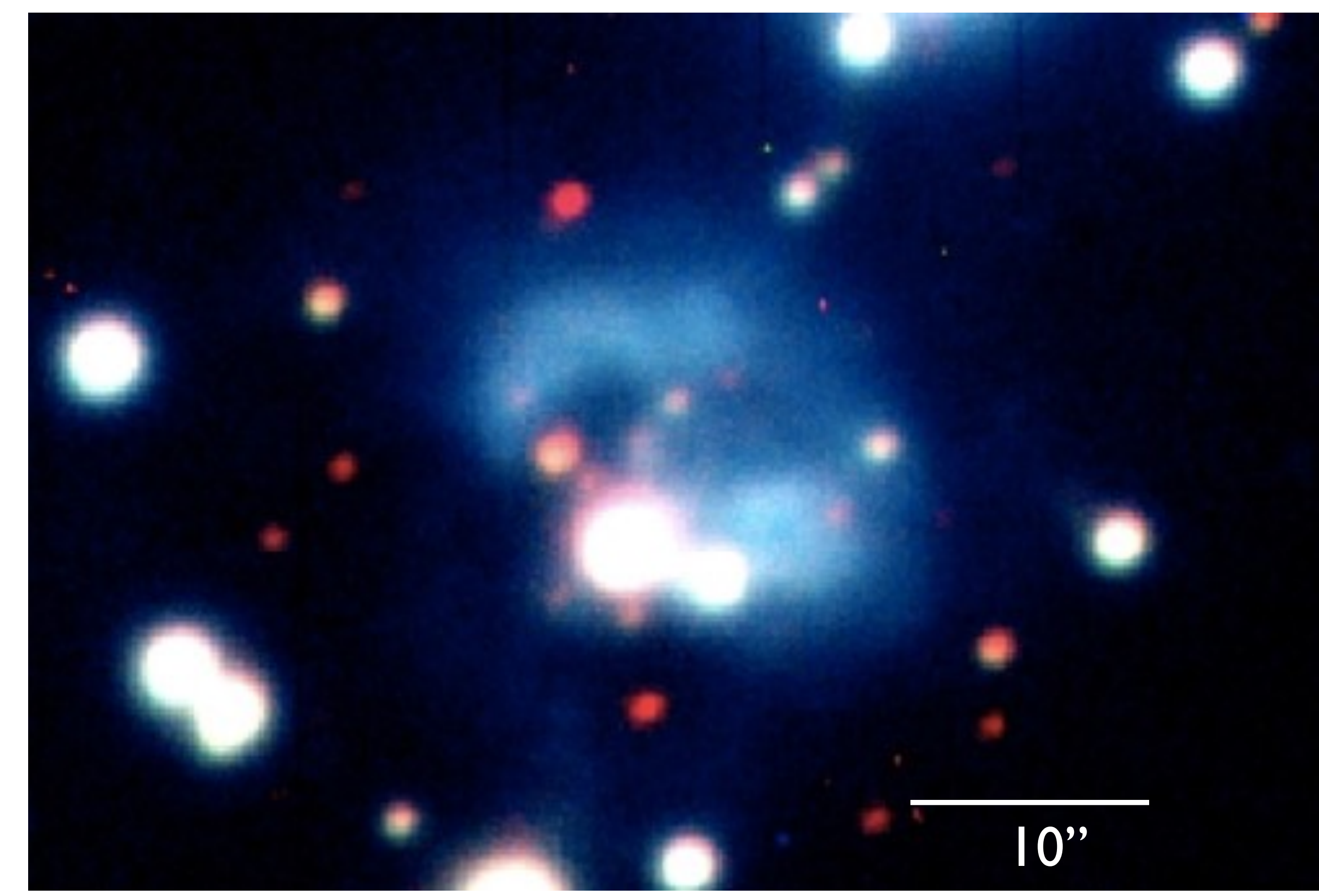
Extended structures

Can be use to understand passed events / early state of RCB stars



Clayton et al., 2011 (~V band)

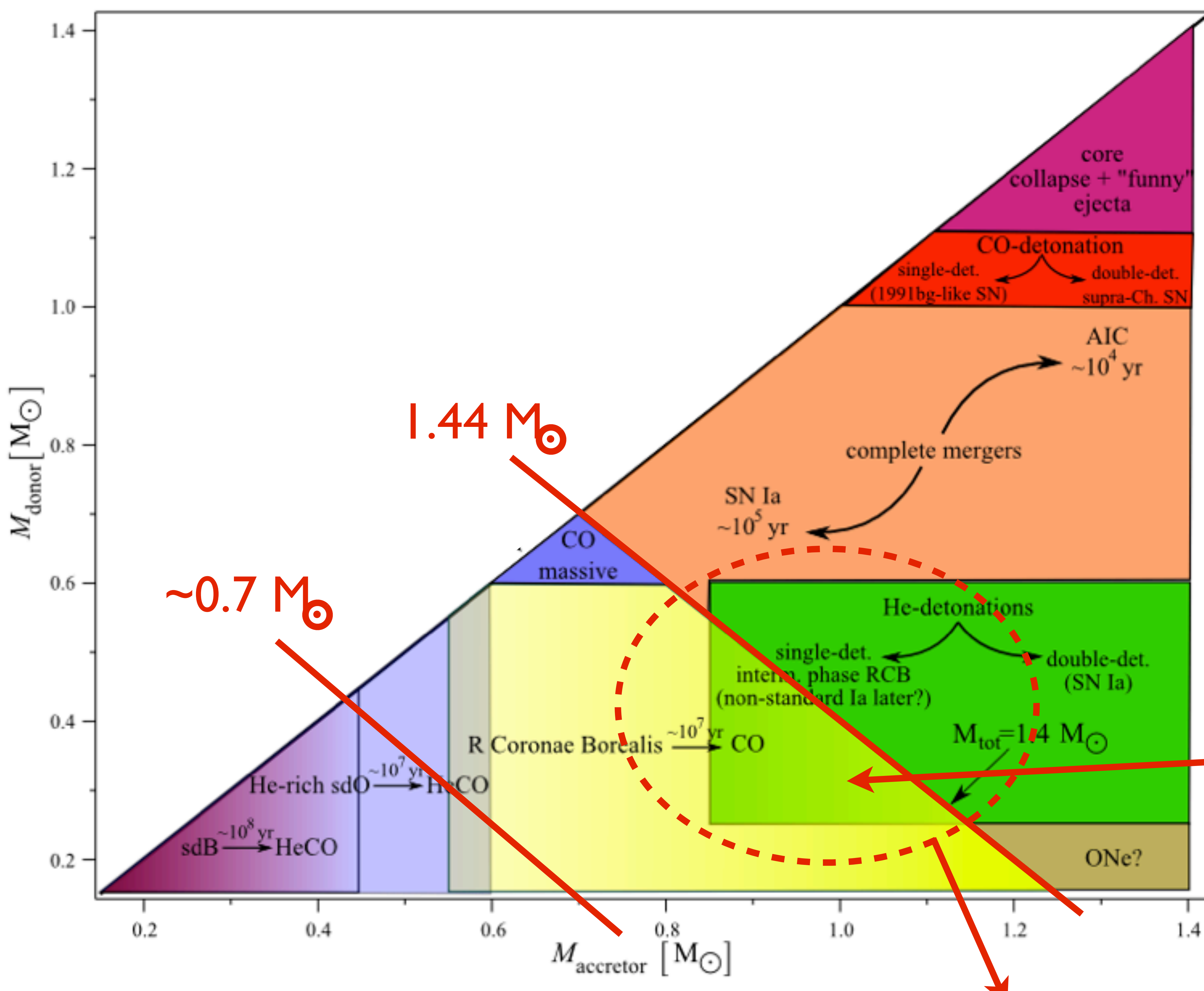
Fig. 7.— *HST/WFPC2* F555W image (17″ x 17″) of R CrB (left) and WFPC2 606W image (12″ x 12″) of UW Cen (right). The inset shows the cometary globule (#1) to the lower left of R CrB.



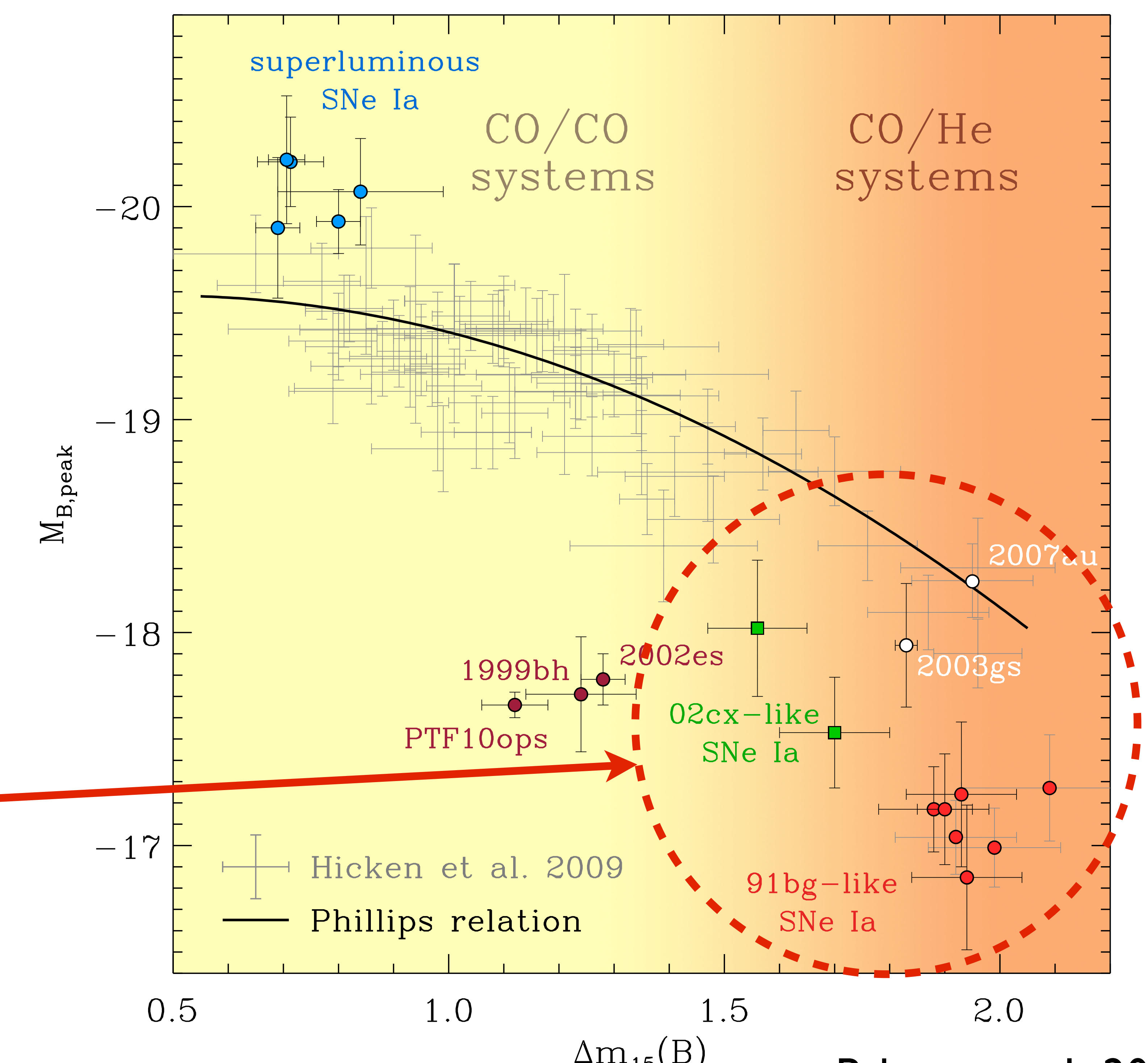
GEMINI-GMOS (2012)
Colour = (g,r,z)

GeMS/GSAOI on GEMINI-South would be ideal for this study on a representative sample of RCB stars

Probe SnIa low mass limit



Sample of sub-luminous, sub-chandrasekhar SNIa :



Pakmor et al., 2013

RCB stars can be used to probe a mass domain where denotation can occur for low-mass CO white-dwarf.

CO + Helium WD merger : double detonation model

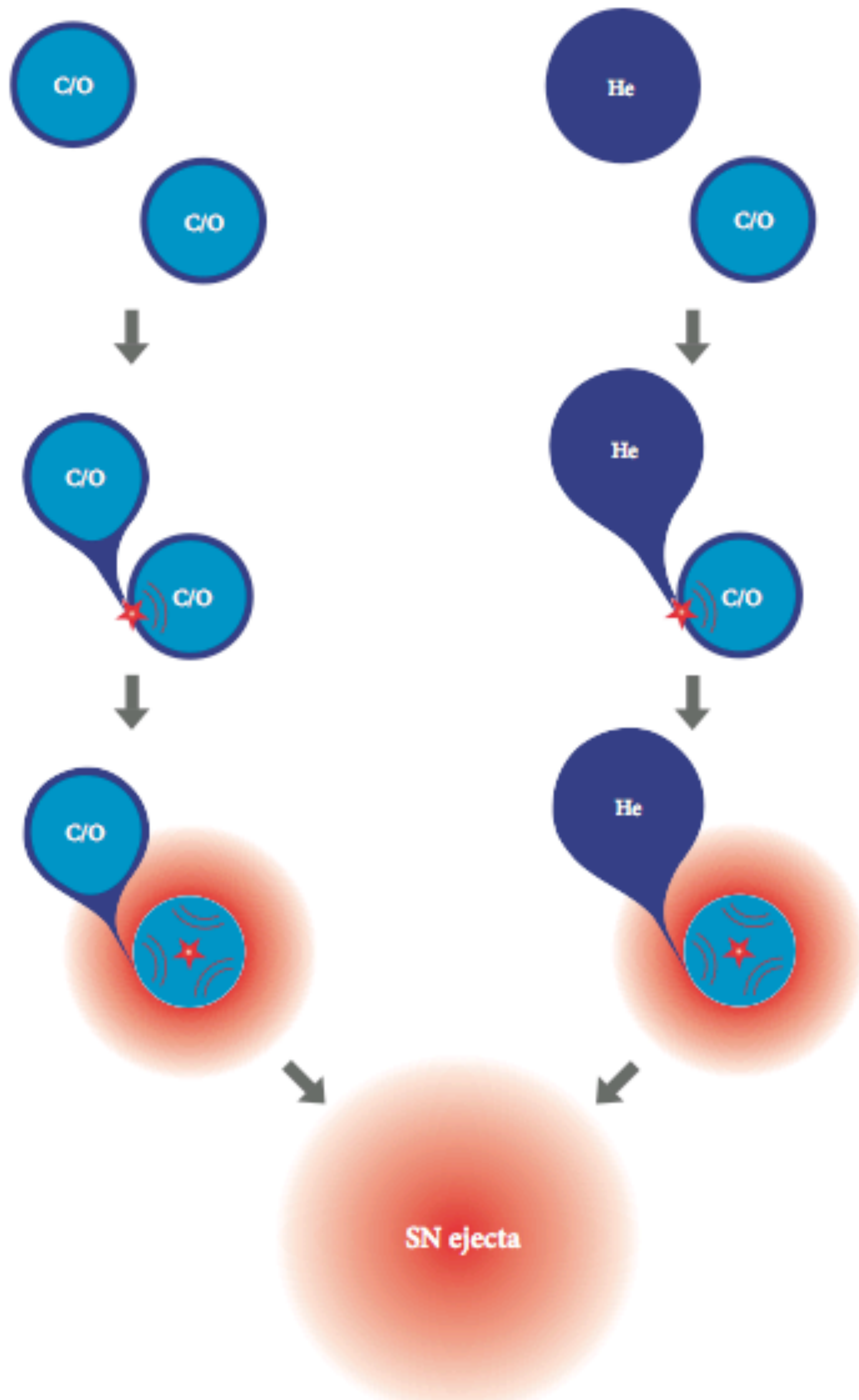


Figure 1. In the helium-ignited violent merger model a detonation forms in the thin He shell of a CO WD, either by the impact of the secondary WD or by accretion instabilities. Once a helium-shell detonation has been ignited, a converging shock runs through the CO core and triggers a secondary CO detonation that completely disrupts the system. The proposed mechanism works both for CO- and He-WD companions (as indicated by the two branches in the figure).

Pakmor et al., 2013

2D simulations of the double-detonation model for thermonuclear transients from low-mass carbon–oxygen white dwarfs

S. A. Sim,[1★] M. Fink,[2,3] M. Kromer,[3] F. K. Röpke,[2,3] A. J. Ruiter[3] and W. Hillebrandt[3]

2012MNRAS.420.3003S

ABSTRACT

Thermonuclear explosions may arise in binary star systems in which a carbon–oxygen (CO) white dwarf (WD) accretes helium-rich material from a companion star. If the accretion rate allows a sufficiently large mass of helium to accumulate prior to ignition of nuclear burning, the helium surface layer may detonate, giving rise to an astrophysical transient. Detonation of the accreted helium layer generates shock waves that propagate into the underlying CO WD. This might directly ignite a detonation of the CO WD at its surface (an edge-lit secondary detonation) or compress the core of the WD sufficiently to trigger a CO detonation near the centre. If either of these ignition mechanisms works, the two detonations (helium and CO) can then release sufficient energy to completely unbind the WD. These 'double-detonation' scenarios for thermonuclear explosion of WDs have previously been investigated as a potential channel for the production of Type Ia supernovae from WDs of $\sim 1\,M_{\odot}$. Here we extend our 2D studies of the double-detonation model to significantly less massive CO WDs, the explosion of which could produce fainter, more rapidly evolving transients. We investigate the feasibility of triggering a secondary core detonation by shock convergence in low-mass CO WDs and the observable consequences of such a detonation. Our results suggest that core (…)

We concluded that, if detonation of the He layer occurs, the resulting compression and heating of the CO core by inwardly propagating shocks can produce sufficiently high densities and temperatures that core detonation may occur, even for core masses as low as $0.45\,M_{\odot}$. Together with previous results (Livne & Arnett 1995; Fink et al. 2010), this suggests that detonation of an accreted He layer (as in the p-Ia scenario of Bildsten et al. 2007) could be accompanied by explosion of the underlying core for all CO core masses that are commonly realized in nature.

Although our results suggest that core detonation is probable in all cases, they do not prove that it must always occur. For example, strong rotation might inhibit the shock convergence. Alternatively, the converging shocks might heat the material around the putative detonation point sufficiently that burning occurs prior to ignition of a detonation. Depending on the geometry, this might mean that the

The ejected mass distribution of type Ia supernovae: A significant rate of non-Chandrasekhar-mass progenitors

2014MNRAS.445.2535S

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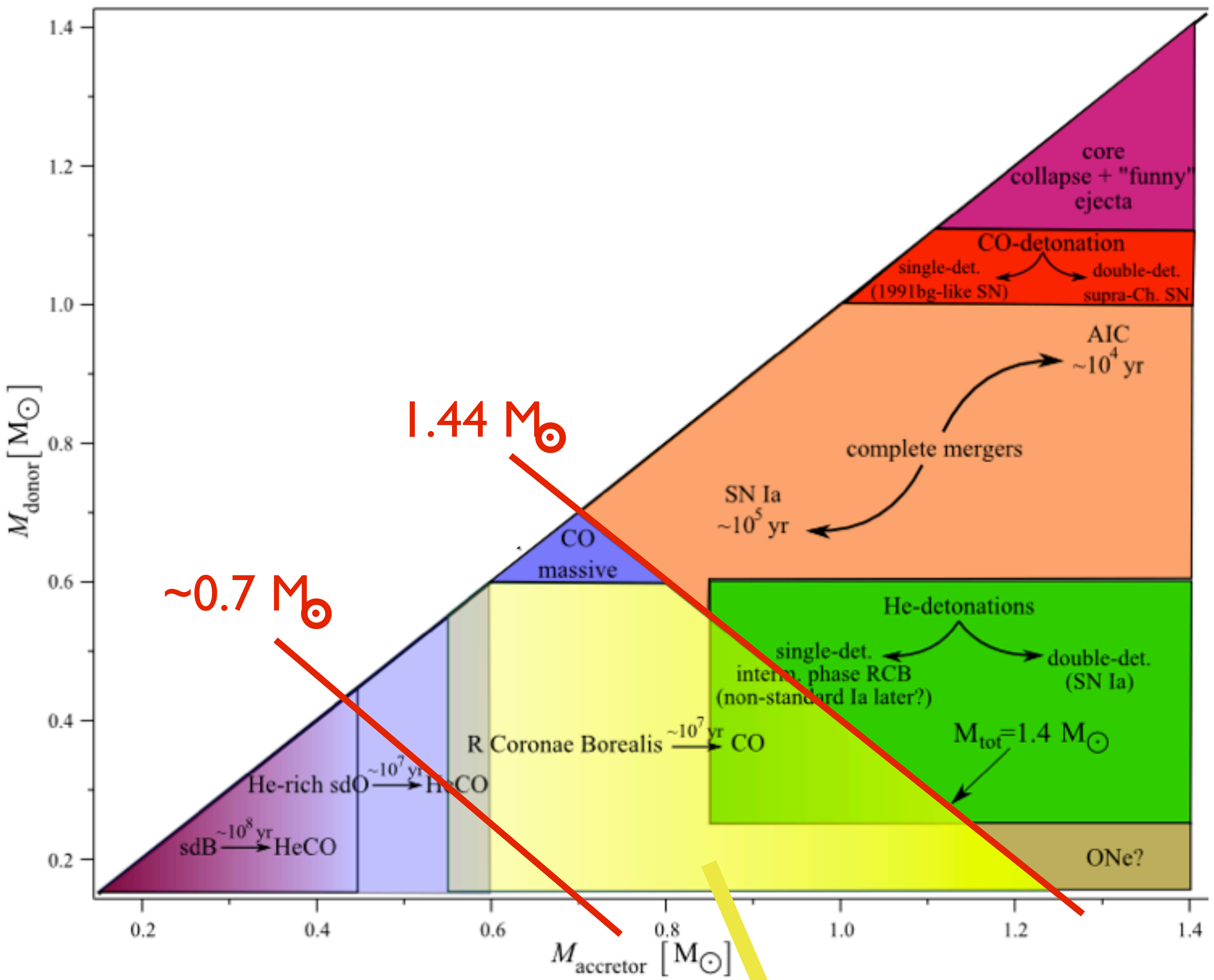
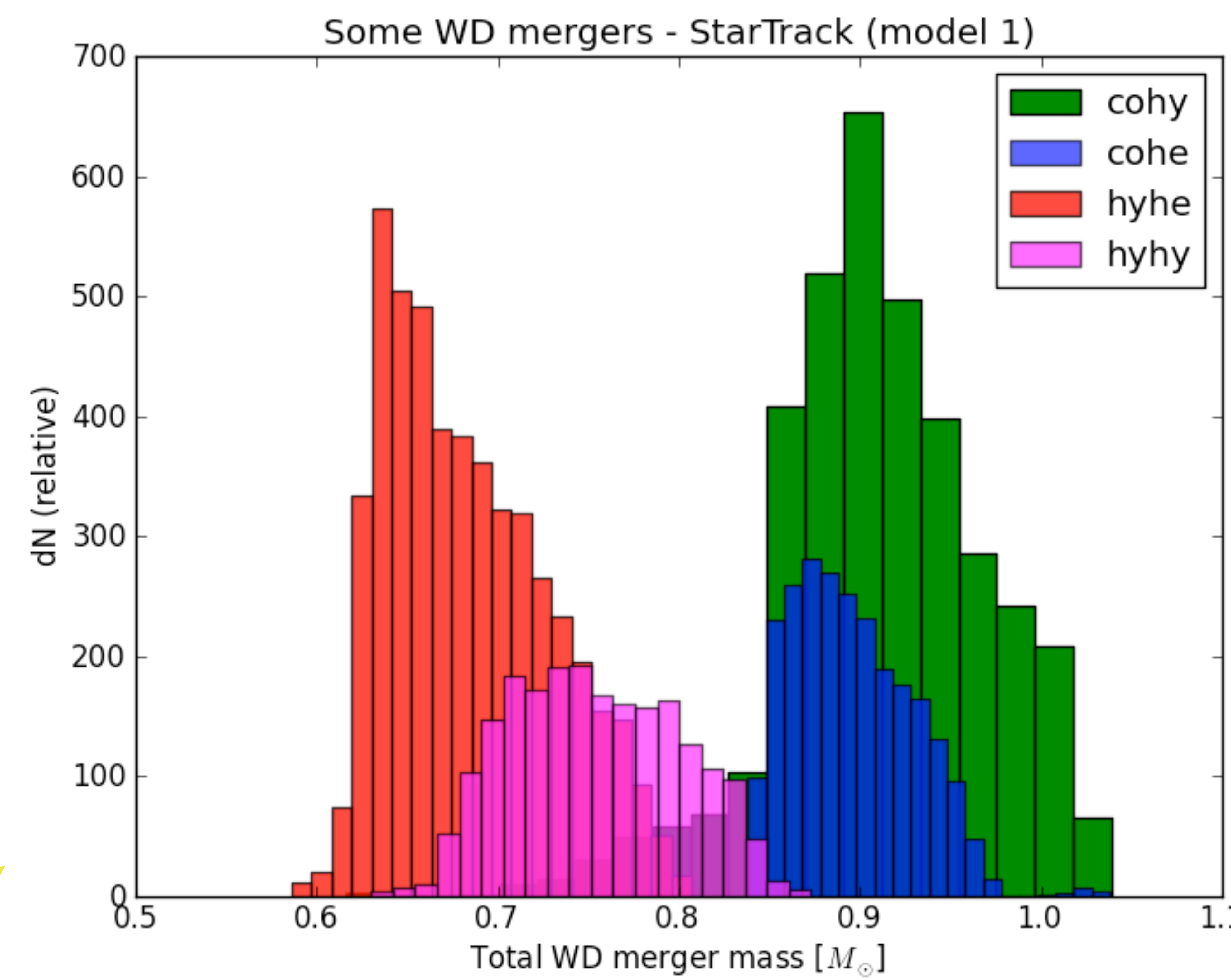
The ejected mass distribution of type Ia supernovae directly probes progenitor evolutionary history and explosion mechanisms, with implications for their use as cosmological probes. Although the Chandrasekhar mass is a natural mass scale for the explosion of white dwarfs as type Ia supernovae, models allowing type Ia supernovae to explode at other masses have attracted much recent attention. Using an empirical relation between the ejected mass and the light curve width, we derive ejected masses $M_{\rm ej}$ and ^{56}Ni masses $M_{\rm Ni}$ for a sample of 337 type Ia supernovae with redshifts $z < 0.7$ used in recent cosmological analyses. We use hierarchical Bayesian inference to reconstruct the joint $M_{\rm ej}$-$M_{\rm Ni}$ distribution, accounting for measurement errors. The inferred marginal distribution of $M_{\rm ej}$ has a long tail towards sub-Chandrasekhar masses, but cuts off sharply above 1.4 $M_\odot$. Our results imply that 25%–50% of normal type Ia supernovae are inconsistent with Chandrasekhar-mass explosions, with almost all of these being sub-Chandrasekhar-mass; super-Chandrasekhar-mass explosions make up no more than 1% of all spectroscopically normal type Ia supernovae. We interpret the type Ia supernova width-luminosity relation as an underlying relation between $M_{\rm ej}$ and $M_{\rm Ni}$, and show that the inferred relation is not naturally explained by the predictions of any single known explosion mechanism.

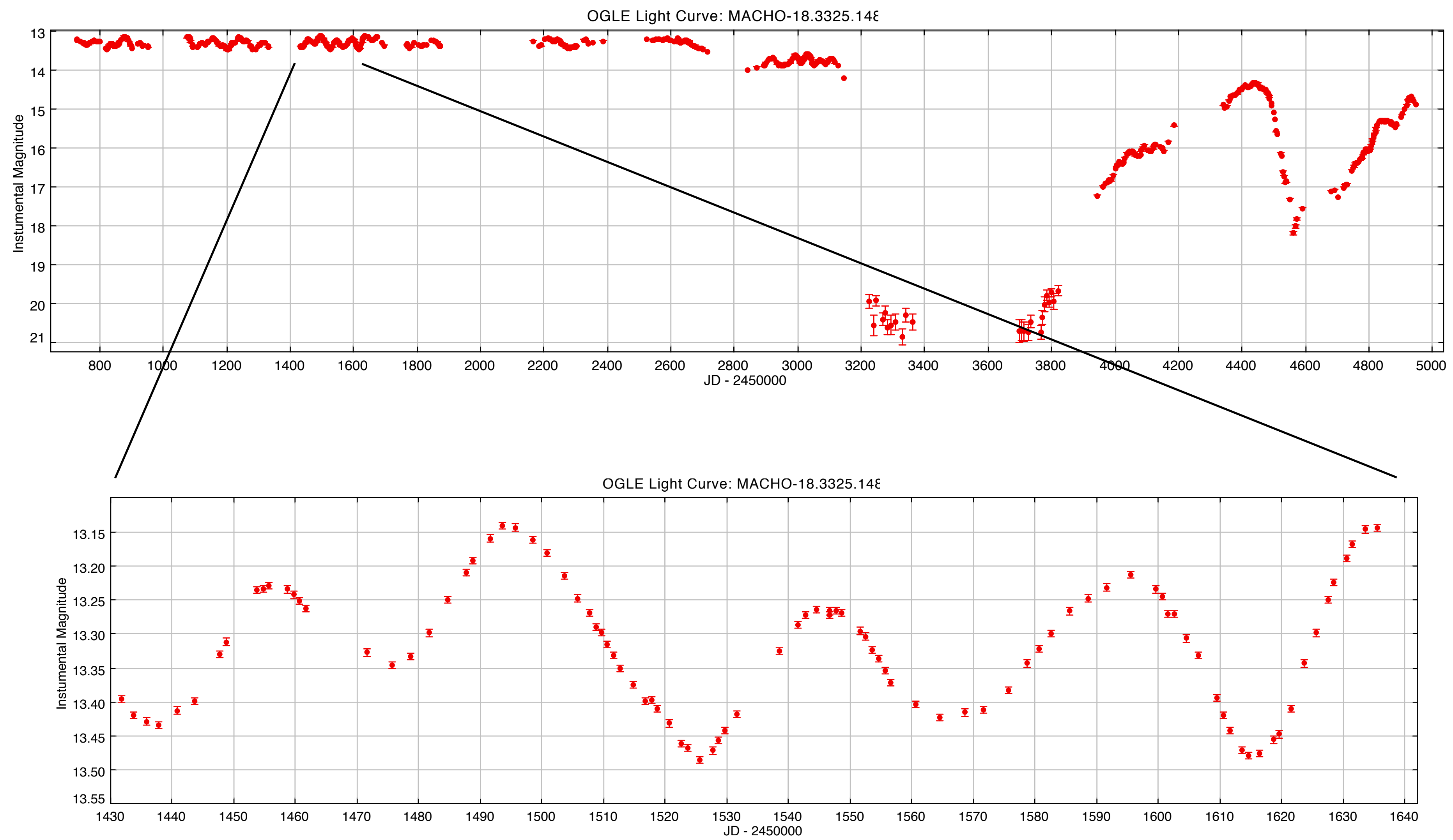
Mass distribution of RCB stars if no CO+He WDs mergers explode :

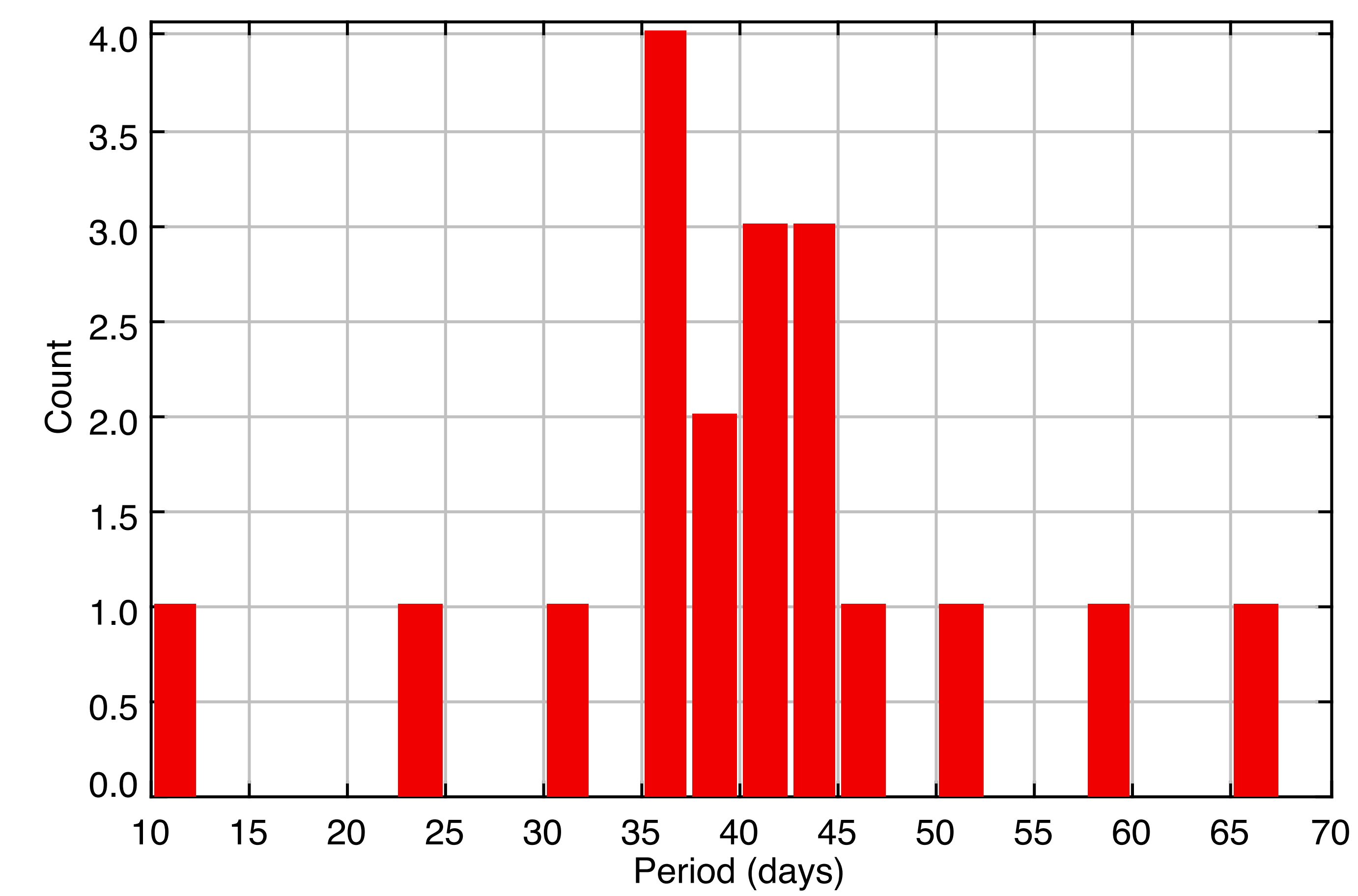




Ruiter A. J. (2013, Max-Planck Institute)

Determination of RCB's mass using Pulsation model





$$P_o \sim R^{\frac{3}{2}} M^{-\frac{1}{2}}$$

Model atmosphere + C opacity

→ Need to accumulate statistics to determine the highest mass domain possible for RCB stars

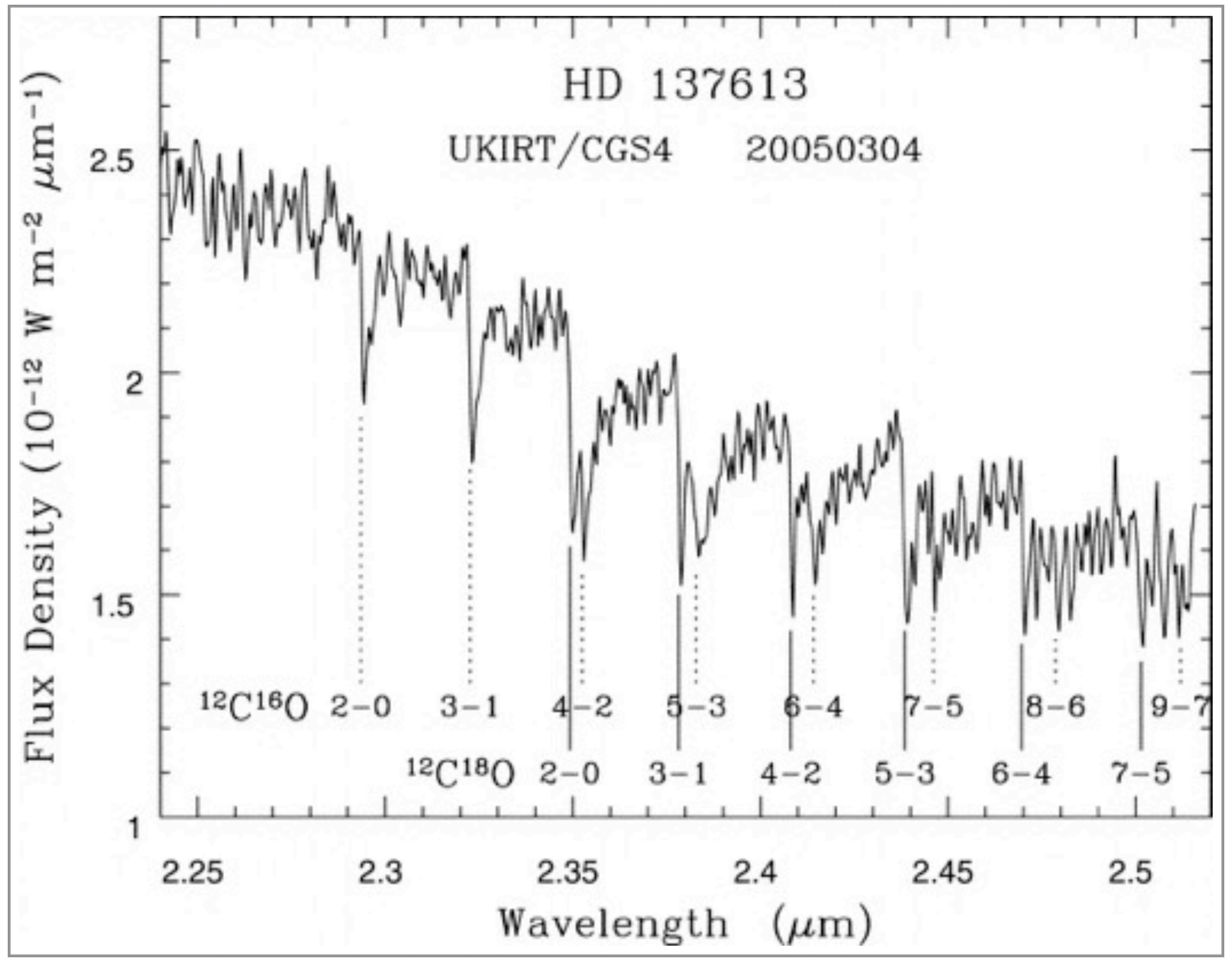
Using for the moment Magellanic RCB stars only.
With GAIA, we will be able to do the same with hundreds of Galactic RCBs.

Problems to solve:

- *Astronomy :*
  - Statistics ** Key **
  - Spatial distribution
  - Population type
- *Evolution :*
  - Origin and fate **
  - Links between classes
- Physics :
  - Atmospheres / Nucleosynthesis
  - Pulsations / Masses **
  - Mass loss
  - Merger simulation

RCBs can help:

- to improve merger models
- to calibrate rate / pop. synthesis model
- probe lower mass limit of SN Ia progenitor in DD scenario



16O/18O ~ 1 observed in RCB stars
but this ratio ~ 500 in the sun.
(Clayton, 2005 & 2007, Garcia-Hernandez, 2010)

$$\left\{\begin{array}{lr} {}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{18}_{9}\mathrm{F} + \gamma & (\alpha \text{ capture}) \\ {}^{18}_{9}\mathrm{F} \longrightarrow {}^{18}_{8}\mathrm{O} + \nu + p & (\beta + \text{decay}) \end{array}\right.$$

<u>*Clayton (2007)*</u> : Rapid Hot Merger (T~ 10^8K) - There are some partial He burning… But need also admixture of H from the WD-CO to obtain the abundances of s-process element observed in HdC and RCB stars.

<u>*Jeffery, Karakas, Saio (2011)*</u> : They looked at the surface abundances that arise from a 'cold' and 'hot' merger using the state-of-the-art calculations of the element composition of AGB intershell regions - in both cases, they can find a solution to obtain observed surface abundances.

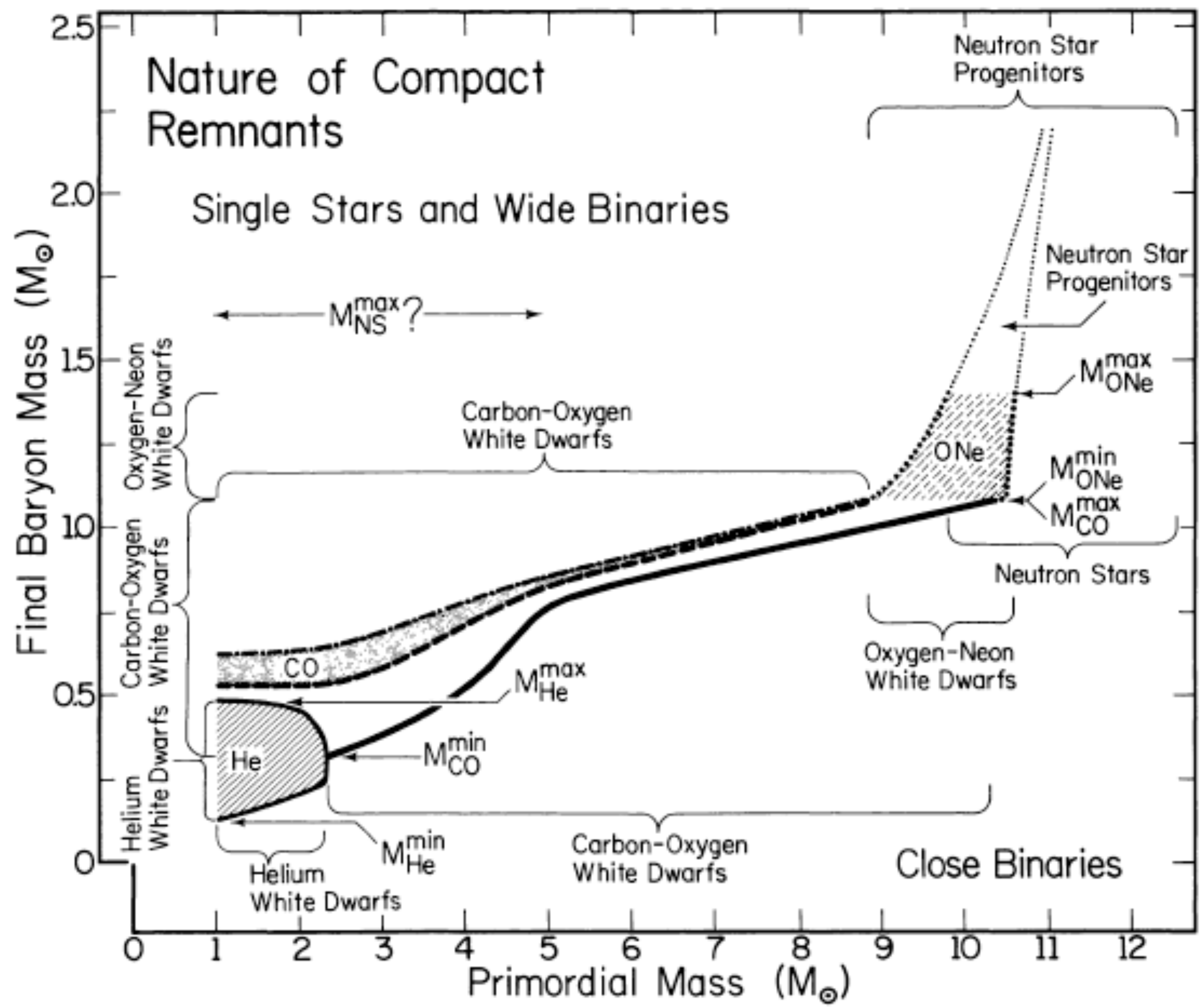


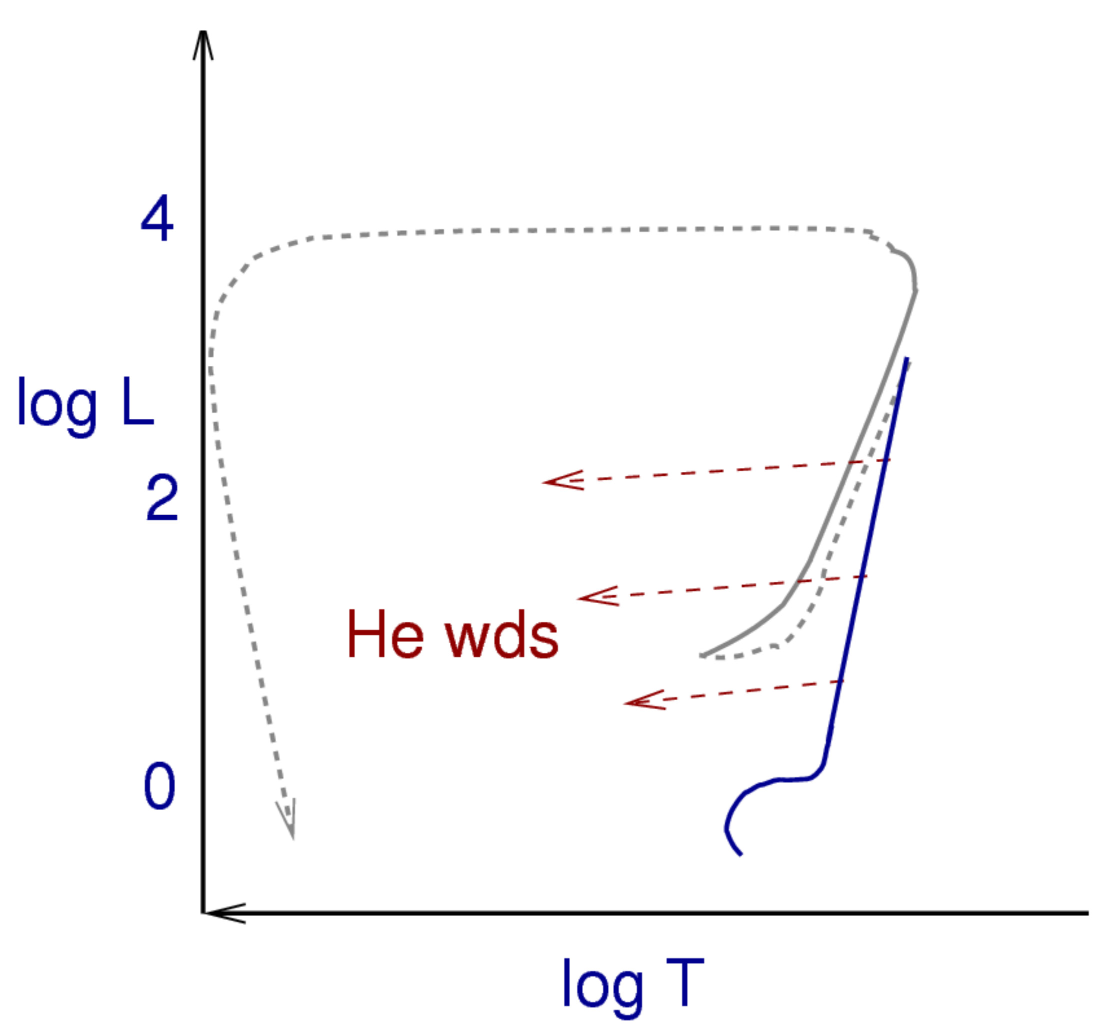
FIG. 30.—The masses and compositions of degenerate dwarfs formed by single stars and by components of interacting binaries. The solid curve extending from 2.3 $M_\odot$ to 10.3 $M_\odot$ is the upper bound on the masses of CO degenerate dwarfs formed in close binaries (first Roche-lobe overflow just before or just after the ignition of central helium). The lower solid curve extending from 1 $M_\odot$ to 2.3 $M_\odot$ is the lower bound on masses of helium degenerate dwarfs formed by stars in close binaries which experience Roche-lobe overflow immediately after forming an electron-degenerate core composed of helium. The upper solid curve extending from 1 $M_\odot$ to 2.3 $M_\odot$ is the upper bound on masses of helium degenerate dwarfs formed in close binaries. The unshaded region gives the possible range in masses of CO degenerate dwarfs formed in wide binaries by components which experience Roche-lobe overflow for the first time during the early AGB phase. The shaded region between the dash and dash-dot curves gives the range in masses of CO degenerate dwarfs formed in wide binaries by components that first experience Roche-lobe overflow during the thermally pulsing AGB (TP–AGB) phase. The dash-dot curve is an estimate of the masses of CO degenerate dwarfs formed by single stars in consequence of mass loss during the TP–AGB phase. Single stars and components of wide binaries cannot form helium degenerate dwarfs or oxygen-neon degenerate dwarfs. In close binaries of appropriate initial configuration, components of initial mass in the range 8.8–10.6 $M_\odot$ may form ONe degenerate dwarfs, with a preponderance being formed by components of initial mass in the range 10.3–10.6 $M_\odot$.

He - White dwarf formation

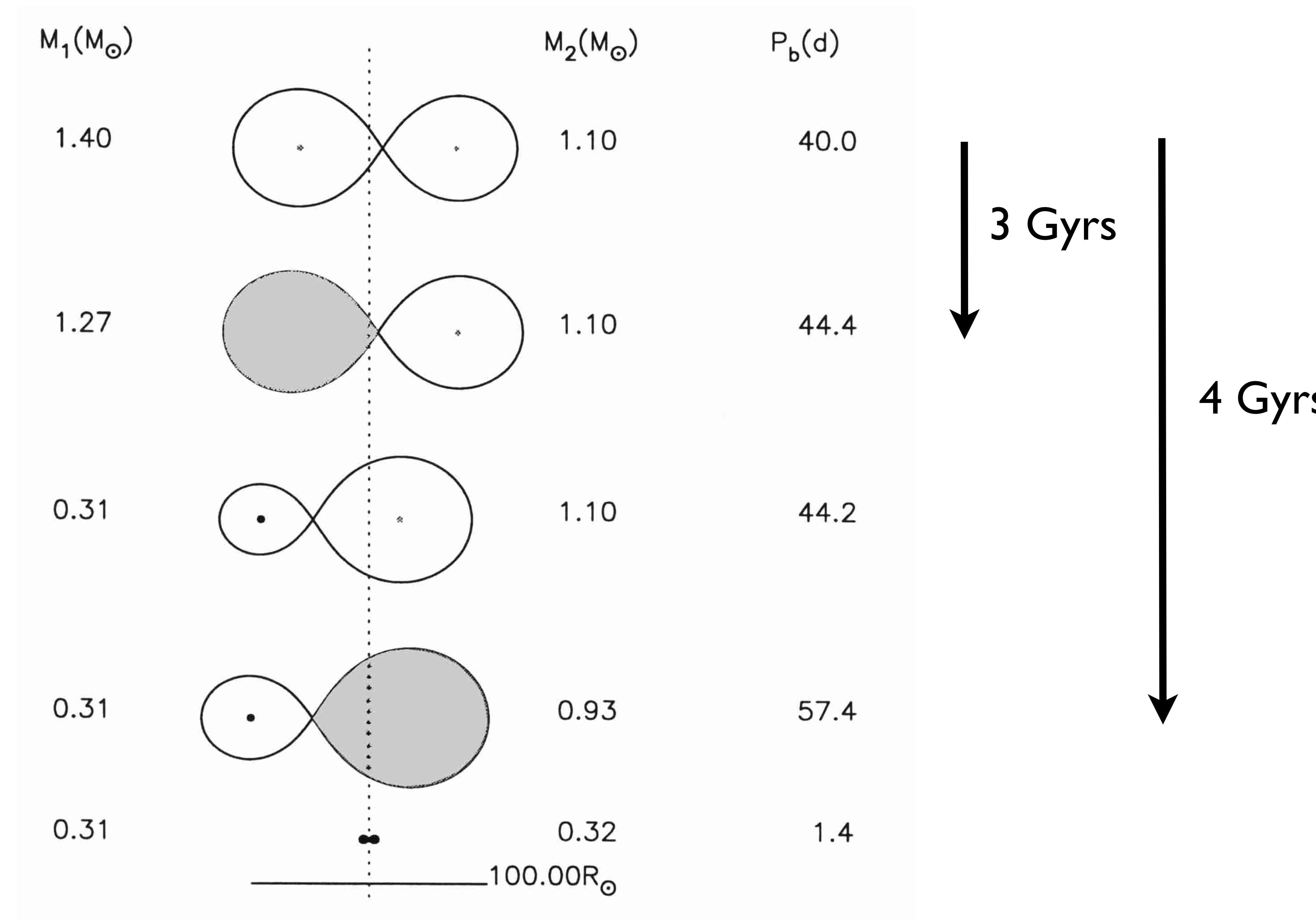
The most common double WDs consist of two Helium WDs

We now know of many helium white dwarfs, and, as expected, they are often associated with binarity and mass transfer.

A helium white dwarf can be made if the hydrogen envelope is lost prior to helium ignition, by mass transfer in a binary.



Simplified Evolutionary scenario for the formation of a double He-WD :



These WDs descend from systems in which both stars have M<2.3Msun and fill their Roche lobes before He ignition in their degenerate cores

WD mass distribution

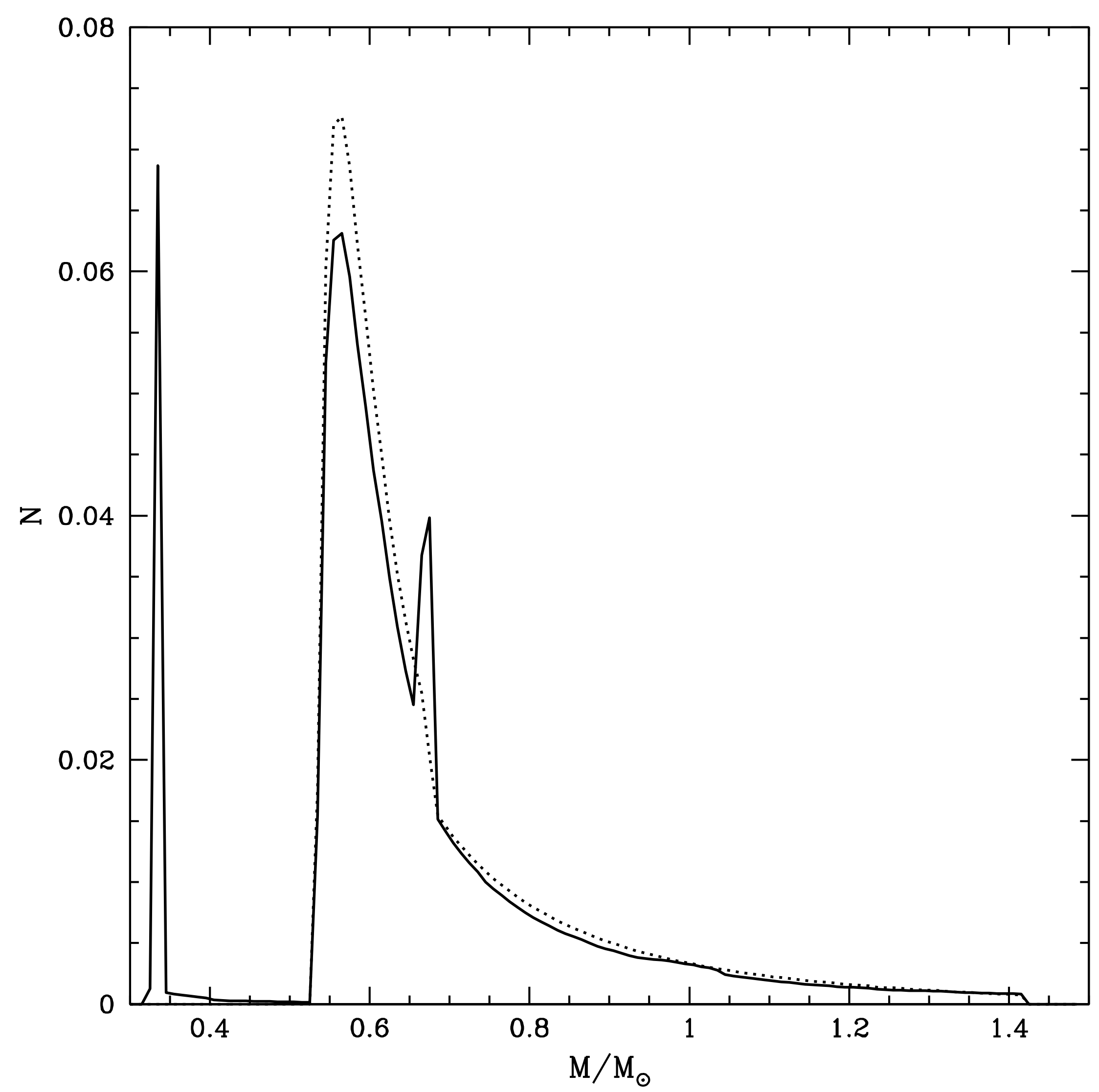


Figure 1. Normalized mass distributions of single white dwarfs (dotted line) and single plus binary white dwarfs (solid line) assuming that all the stars belonging to binary systems have known masses.

Isern et al. (2012)

Mass distribution of WD-WD merger product

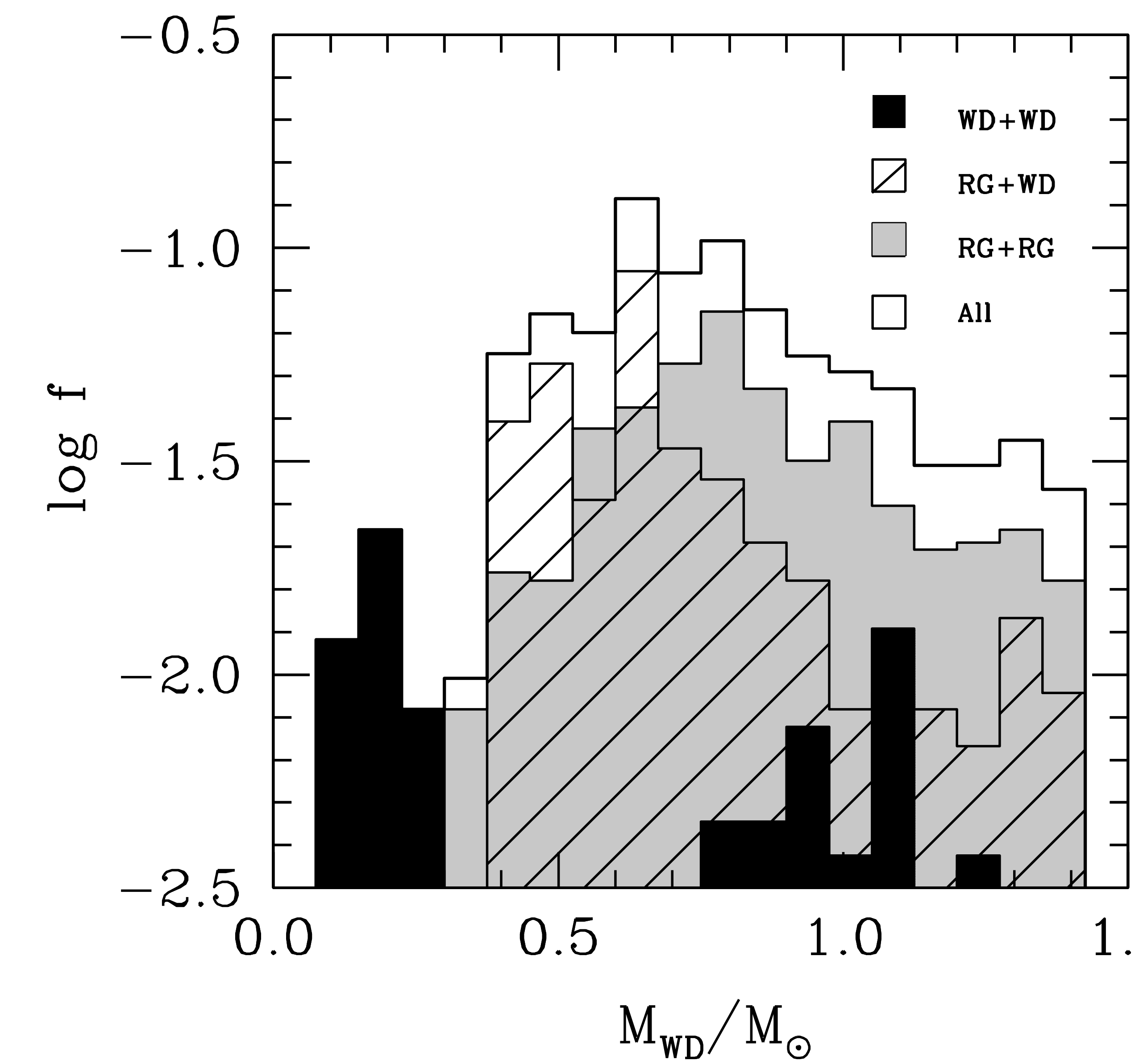


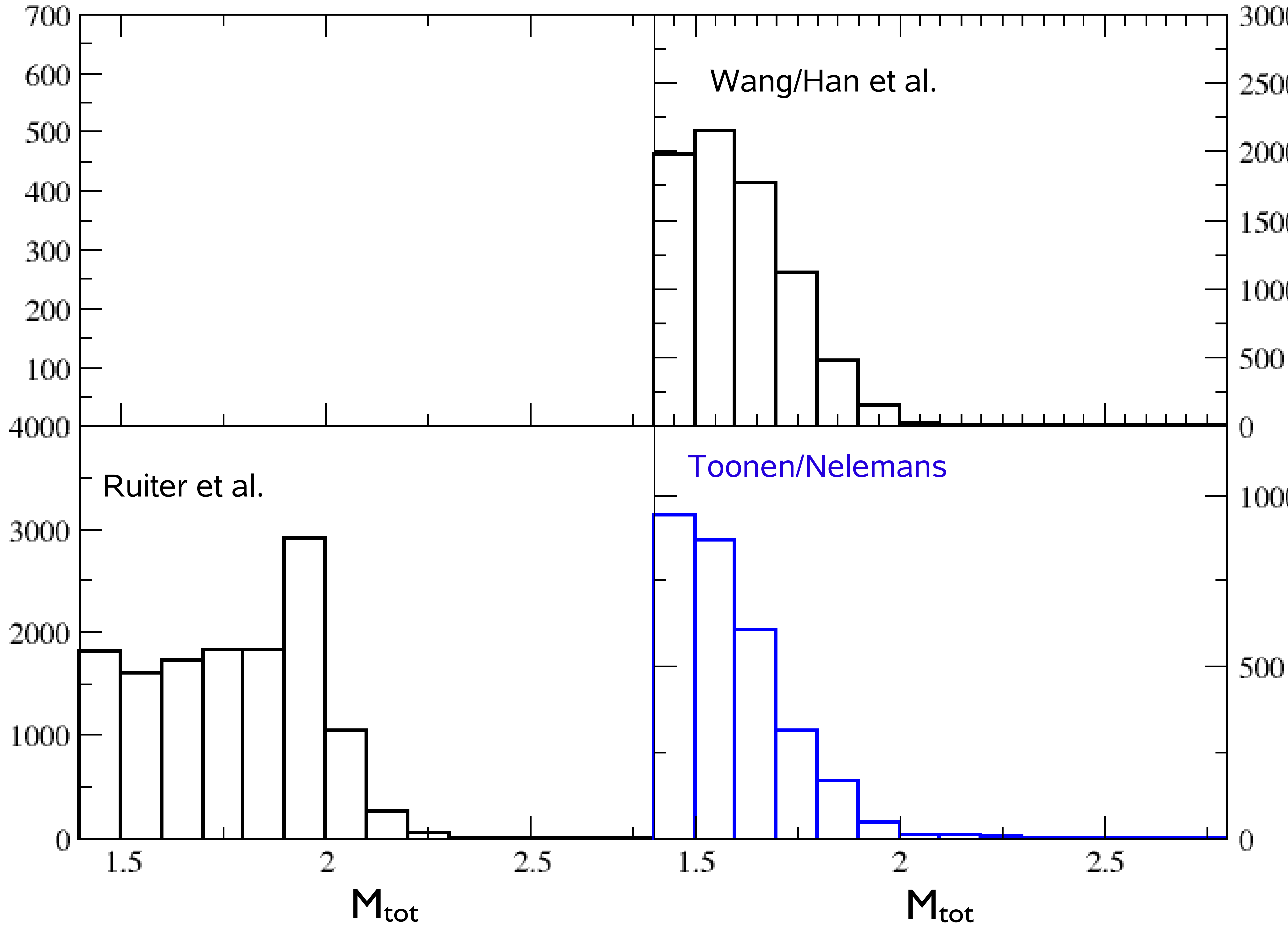
FIG. 2.— Mass distribution of the remnants of the mergers. The distribution shows the frequency of the different merger channels. The black histogram shows the masses of the remnants of the mergers of double white dwarf binaries, the dashed histogram that of the mergers of a binary system composed of a red giant and a white dwarf, the shaded histogram that of the mergers of two red giants, while the total mass distribution is shown using a solid line.

García-Berro et al. (2012)

$M_{tot} = M_1 + M_2/2$

Work in progress from Ashley Ruiter on that distribution (coming soon in 2013 !)

WD CO - CO mergers



$M_{tot} = M_1 + M_2$

Nelemans
(Lorentz center workshop)