DO HYDROGEN-DEFICIENT CARBON STARS HAVE WINDS?

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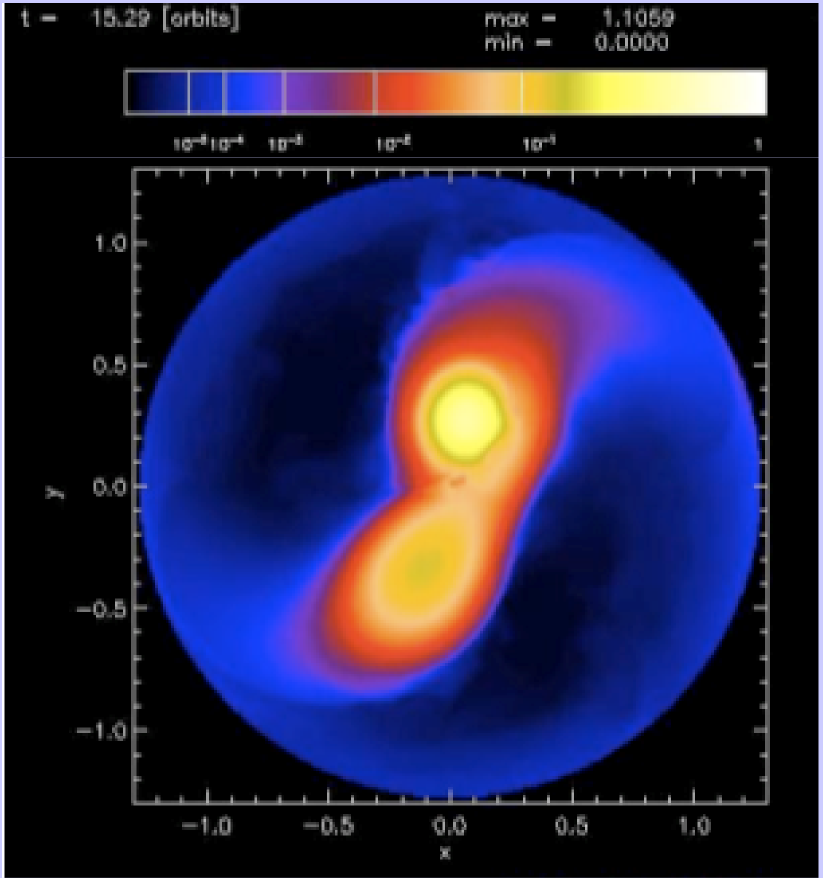
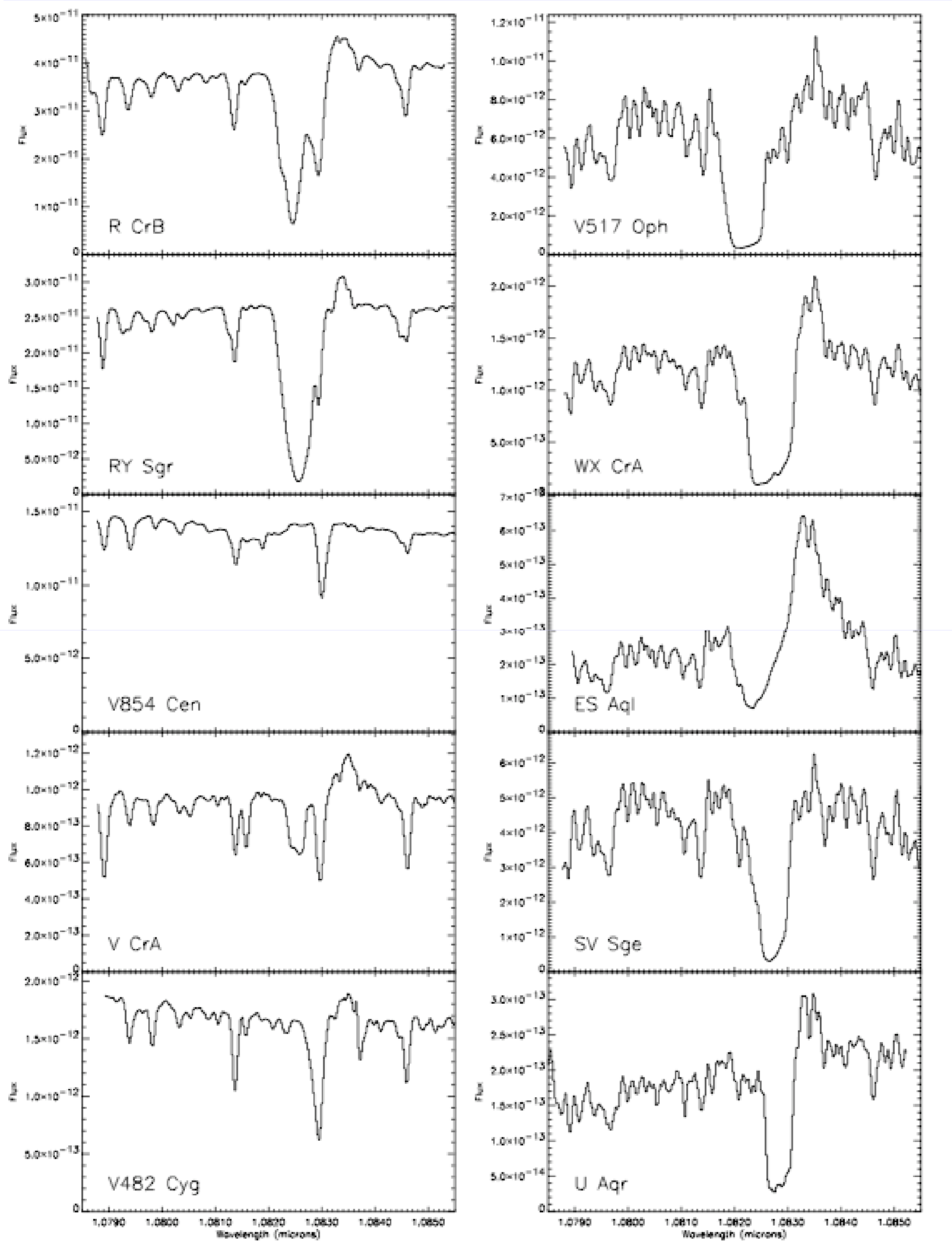
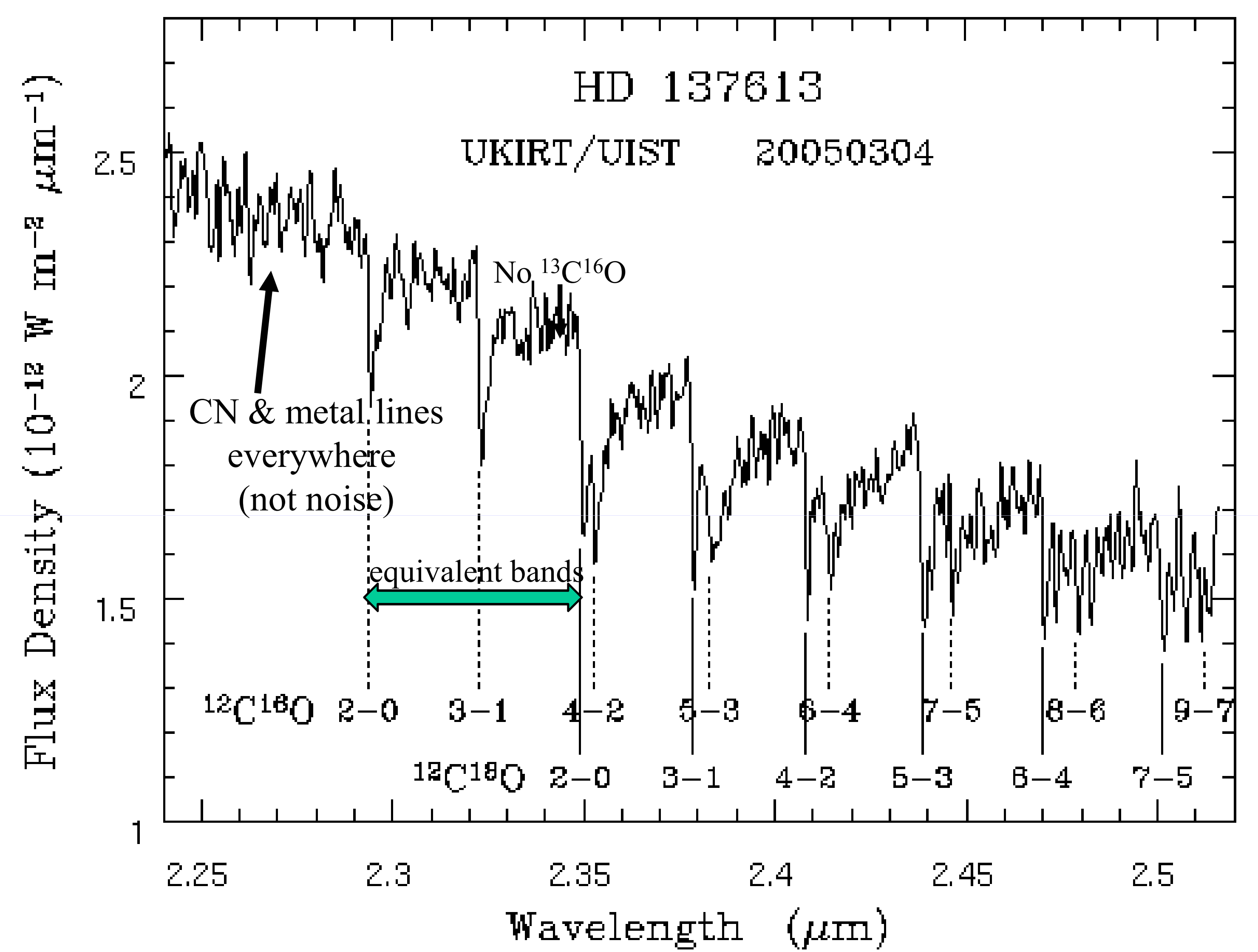




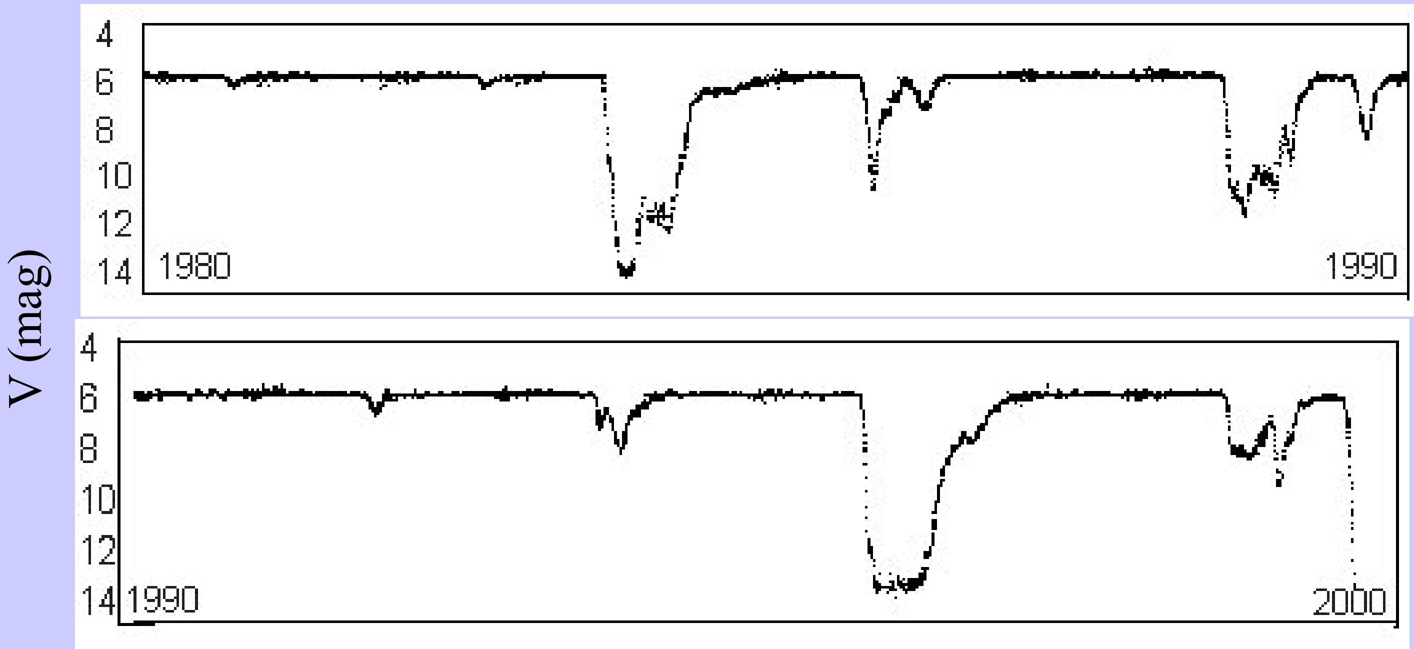
$^{16}O/^{18}O \approx 1$ in an HdC star



Eight bands of $^{12}C^{16}O$, six of $^{12}C^{18}O$; none of any other isotopomers.
^{18}O is overabundant (^{16}O is not underabundant)

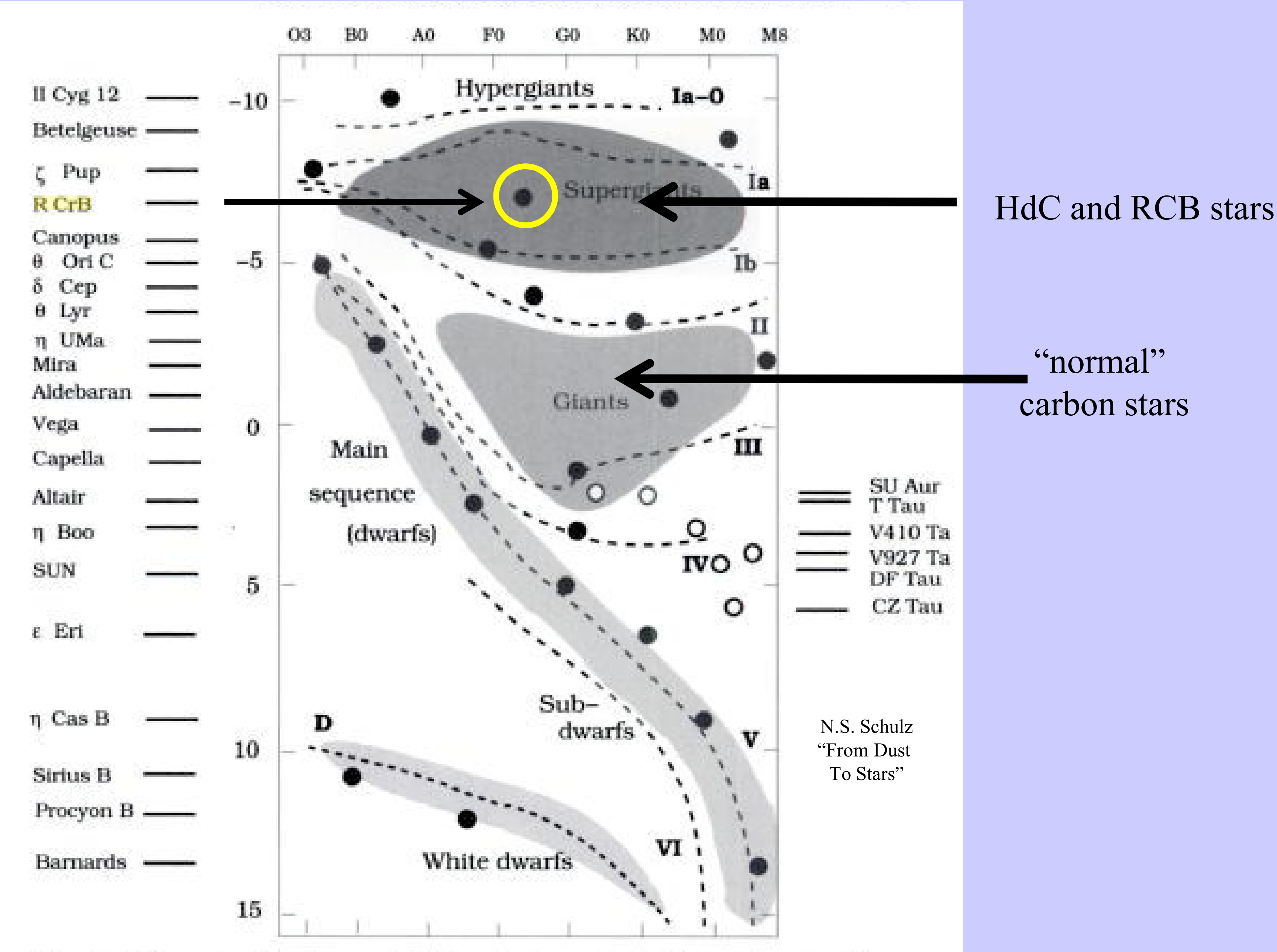
Hydrogen-deficient carbon stars (HdC's)

- [C]>[O]
- Hydrogen deficient by factor of 10^2 - $>10^5$
- Only five are known
- Have chemical abundances and luminosities of RCB stars (~50 known). Are they related?
- Do not vary (unlike RCB stars)



R CrB light curve 1980-2000

RCB and HdC stars are not "normal" carbon stars.



N.S. Schulz
"From Dust
To Stars"

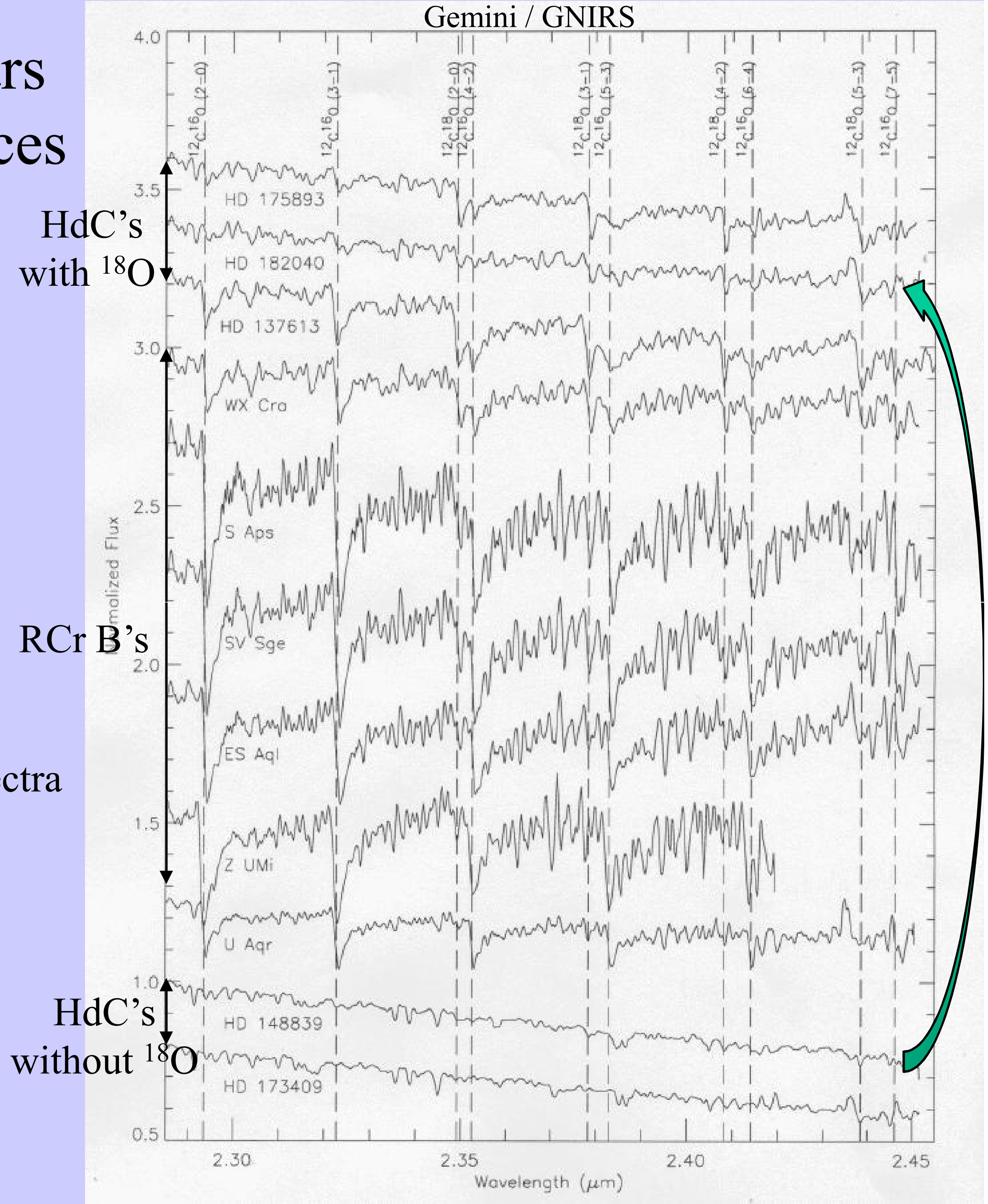
Both HdC and RCB stars have huge overabundances of ^{18}O

- Three additional HdC stars show $^{12}C^{18}O$ bands at least as strong as $^{12}C^{16}O$. (The fourth has no CO at all (too hot)).

- All five cool RCB stars (plus one observed previously) show bands of $^{12}C^{18}O$.

- No sign of ^{13}CO in any of the spectra

Every RCB and HdC star that is cool enough to have CO (so one can search for ^{18}O) has enormously (100X-1000X) enhanced ^{18}O !

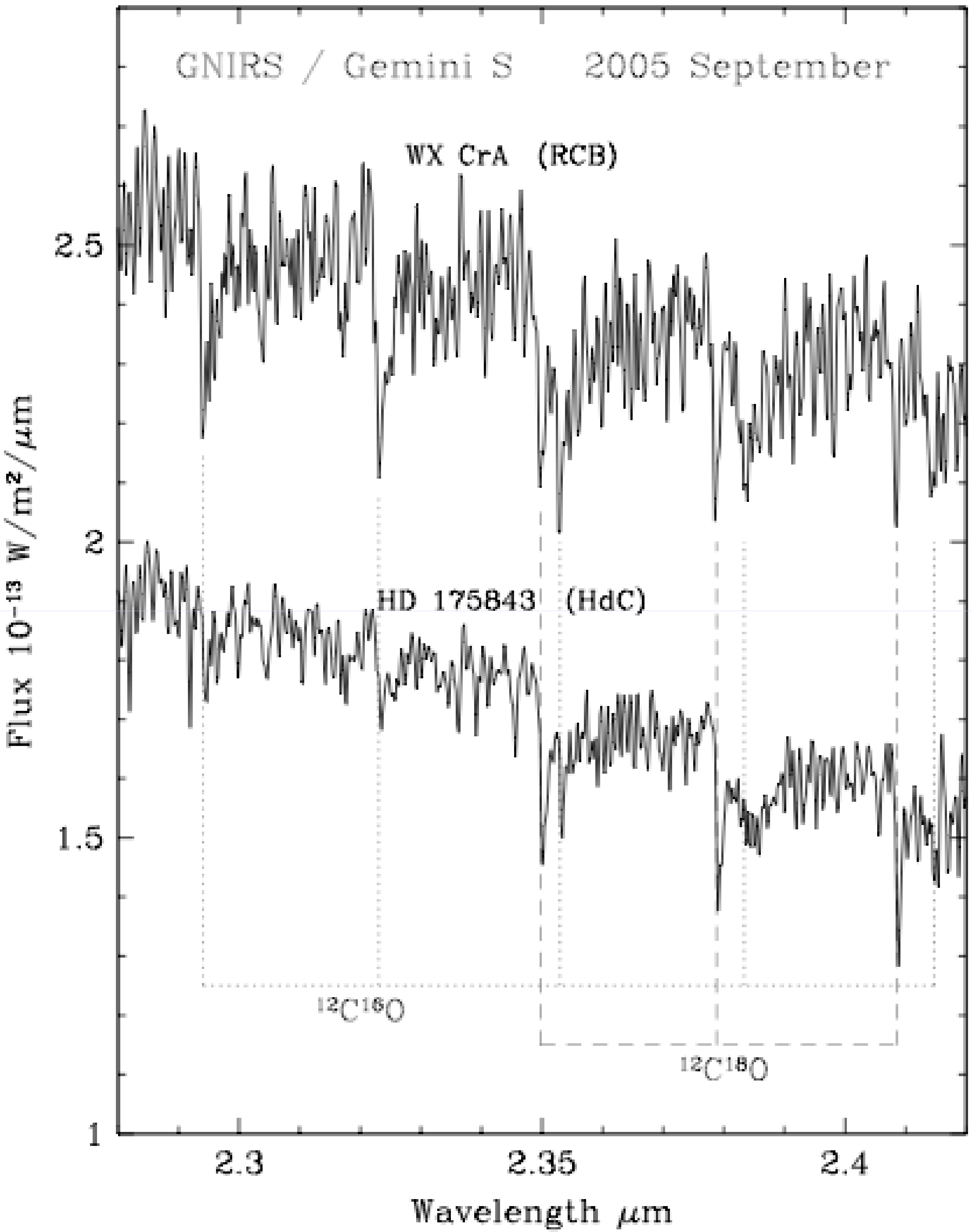


The champions in each class

WX CrA (RCB):
model spectra indicate
$^{16}O/^{18}O \sim 1$

HD 175843 (HdC):
Spectra fitting indicate
$^{16}O/^{18}O \sim 0.2$-0.3 !!
(Clayton et al. 2007,
Garcia-Hernandez et al. 2009)

Interesting pattern:
higher ^{18}O overabundance
in HdC stars ($^{16}O/^{18}O \leq 1$)
than in RCB stars ($^{16}O/^{18}O \geq 1$).



Discovery of enhanced ^{18}O in more HdC stars and in RCB stars allows us to examine the origin of these stars and their ^{18}O

1. *The high ^{18}O abundance in HD 137613 is not a fluke (our initial conclusion), because mass loss by **each** HdC and RCB star **precisely** to the narrow and deeply buried shell of enhanced ^{18}O in evolved stars is impossible. Some reproducible process is occurring.*

2. *The enhanced ^{18}O abundances confirm what was suspected from elemental abundances that the evolutionary paths of HdC's and RCB's are similar (if not identical).*

DOUBLE WHITE DWARFS AS PROGENITORS OF R CORONAE BOREALIS STARS AND TYPE I SUPERNOVAE[1]

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The origin of R CrB stars has been the subject of much discussion and many papers.

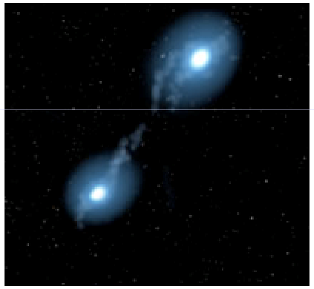
ON THE ORIGIN OF HYDROGEN-DEFICIENT SUPERGIANTS AND THEIR RELATION TO R CORONAE BOREALIS STARS AND NON-DA WHITE DWARFS[1]

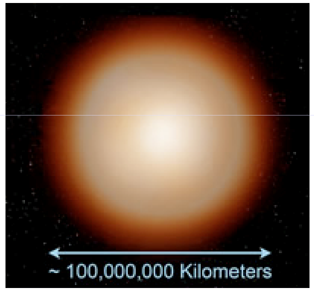
ICKO IBEN, JR.,[2] ALEXANDER V. TUTUKOV,[2,3] AND LEV R. YUNGELSON[3]

Likely origin of RCB stars:
double degenerate merger)

An RCB star is the result of the merger of two white dwarfs
- a helium WD and a C/O WD.

DOUBLE WHITE DWARFS AS PROGENITORS OF R CORONAE BOREALIS STARS AND TYPE I SUPERNOVAE[1]





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ABSTRACT

Close double white dwarfs should arise from the second phase of mass exchange in close binaries which first encountered mass exchange while the more massive star was crossing the Hertzsprung gap. Tidal mass transfer in these double degenerate systems is explored. The sequence of double white dwarfs divides naturally into three segments. (1) Low-mass helium/helium pairs are unstable to dynamical time-scale mass transfer and probably coalesce to form helium-burning sdO stars. (2) In helium/carbon-oxygen pairs, mass transfer occurs on the time scale for gravitational radiation losses ($\sim 10^{-4} M_\odot$ yr^{-1}); the accreted helium is quickly ignited, and the accretor expands to dimensions characteristic of R CrB stars, engulfing its companion star. (3) Carbon-oxygen/carbon-oxygen pairs are again unstable to dynamical time-scale mass transfer and, since their total masses exceed the Chandrasekhar limit, are destined to become supernovae. Inactive lifetimes in these latter systems between creation and interaction can exceed 10^{10} years. Birthrates of R CrB stars and Type I supernovae by evolution of double white dwarfs are in reasonable agreement with observational estimates.

DOUBLE DEGENERATE MODEL: FORMATION OF AN RCB STAR

0. Close binary, brought closer by frictional forces during red giant phases.

1. WD Binary coalesces due to loss of angular momentum by gravitational radiation.

2. He-WD is disrupted.

3. Some of it accretes onto the C/O-WD and starts to burn.

4. Remainder forms a r ~ 100 $R_{\odot}$ envelope.

The number of RCB stars is in very rough accord with the predicted frequency of C/O-WD - He-WD mergers, 1.9 x 10^{-11} pc^{-3} yr^{-1}, and the estimated lifetime of RCB stars (Webbink).

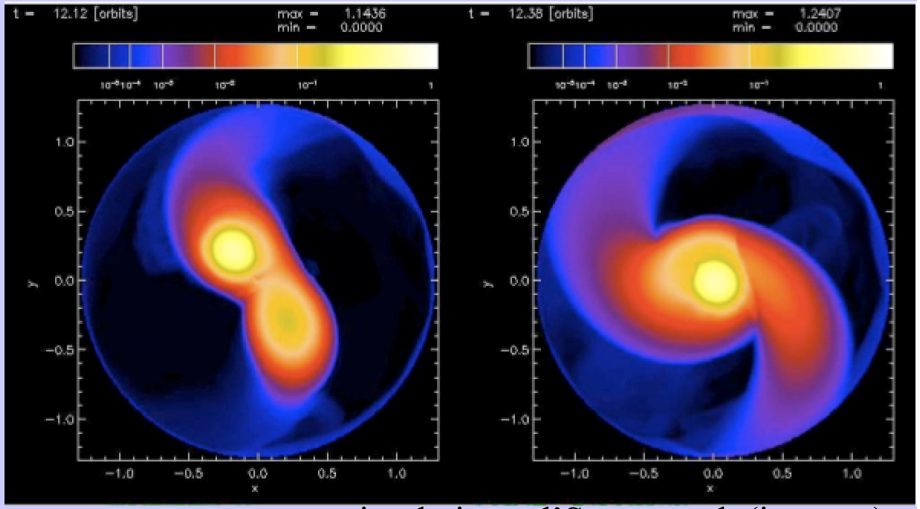
(A) The merger process – Chris Fryer (LANL)

(1) Most of merger happens rapidly (1000 s).

(2) Remaining disk of material from He WD will accrete (over ~several days)

(3) T(WD surface) increases to ~ 1-2 x 10^8 K

(4) Nucleosynthesis occurs for ~100 years



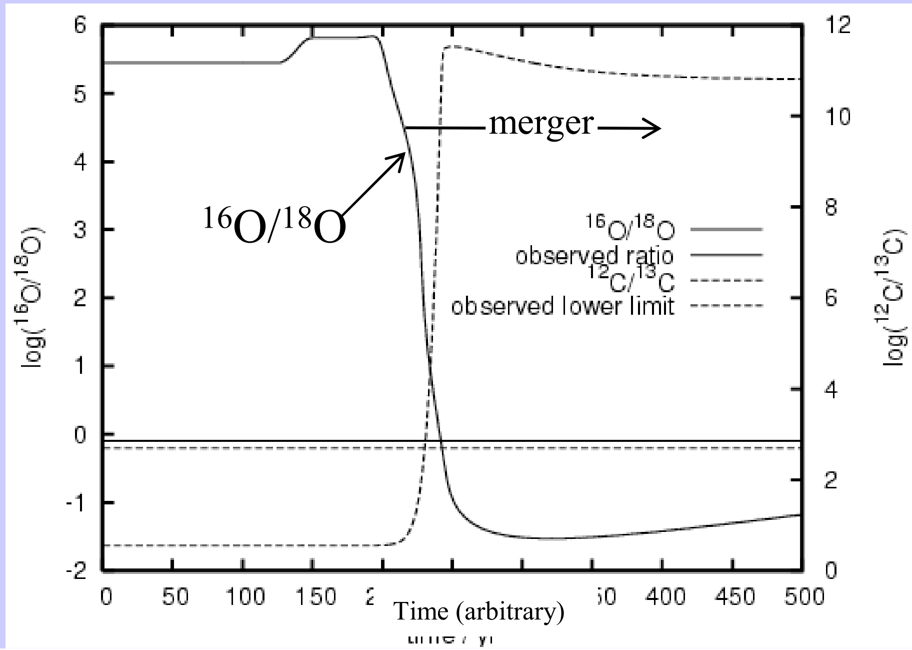
simulation - d'Souza et al. (in prep.)

(B) Nucleosynthesis: One-zone parametric model (density held constant) – Falk Herwig (U Vic.)

Clayton et al. (2007)

^{18}O and ^{13}C:

rapid decrease in $^{16}O/^{18}O$ due to $^{14}N(\alpha,\gamma)^{18}O$
and
rapid increase of $^{12}C/^{13}C$ due to triple- α



Do HdC stars have winds?

1. Spectroscopy of the He I 10830 Å line shows shows that virtually all RCB stars have very energetic winds (Clayton et al. (2003).

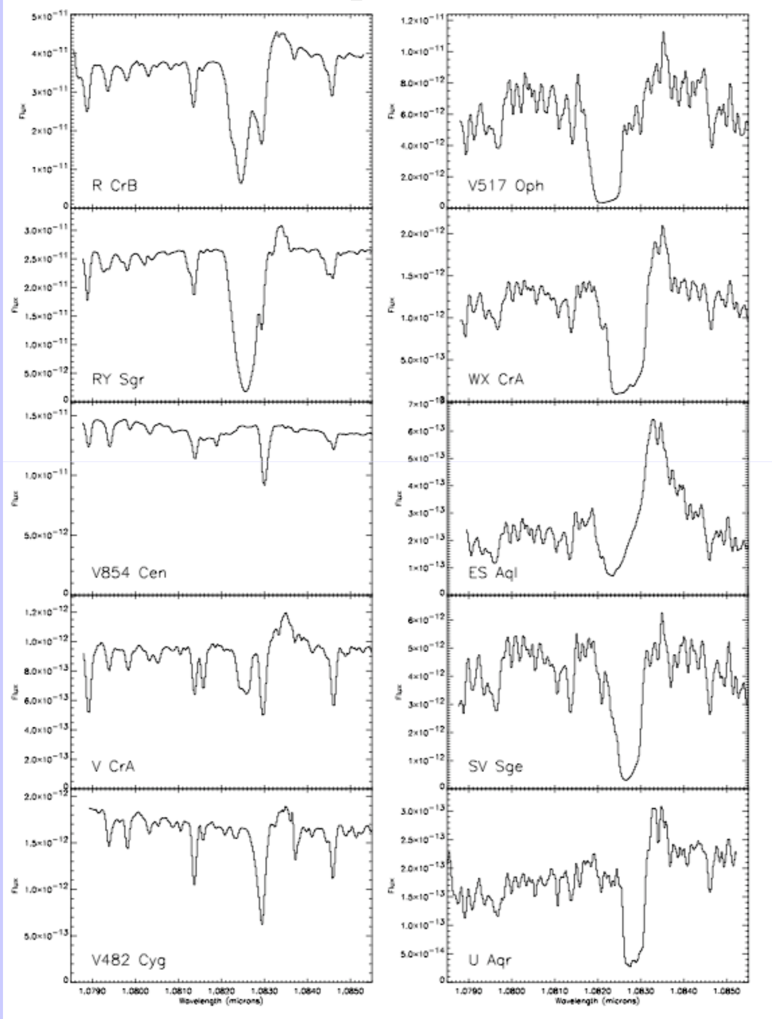
2. He I 10830 Å line strength in RCB stars correlates with dust formation / obscuration (Clayton et al. 2009, in prep.).

3. No information available for HdC stars. (all we know is that dust doesn't form)

4. Naive prediction is no winds in HdC stars (assuming winds are associated with dust production).

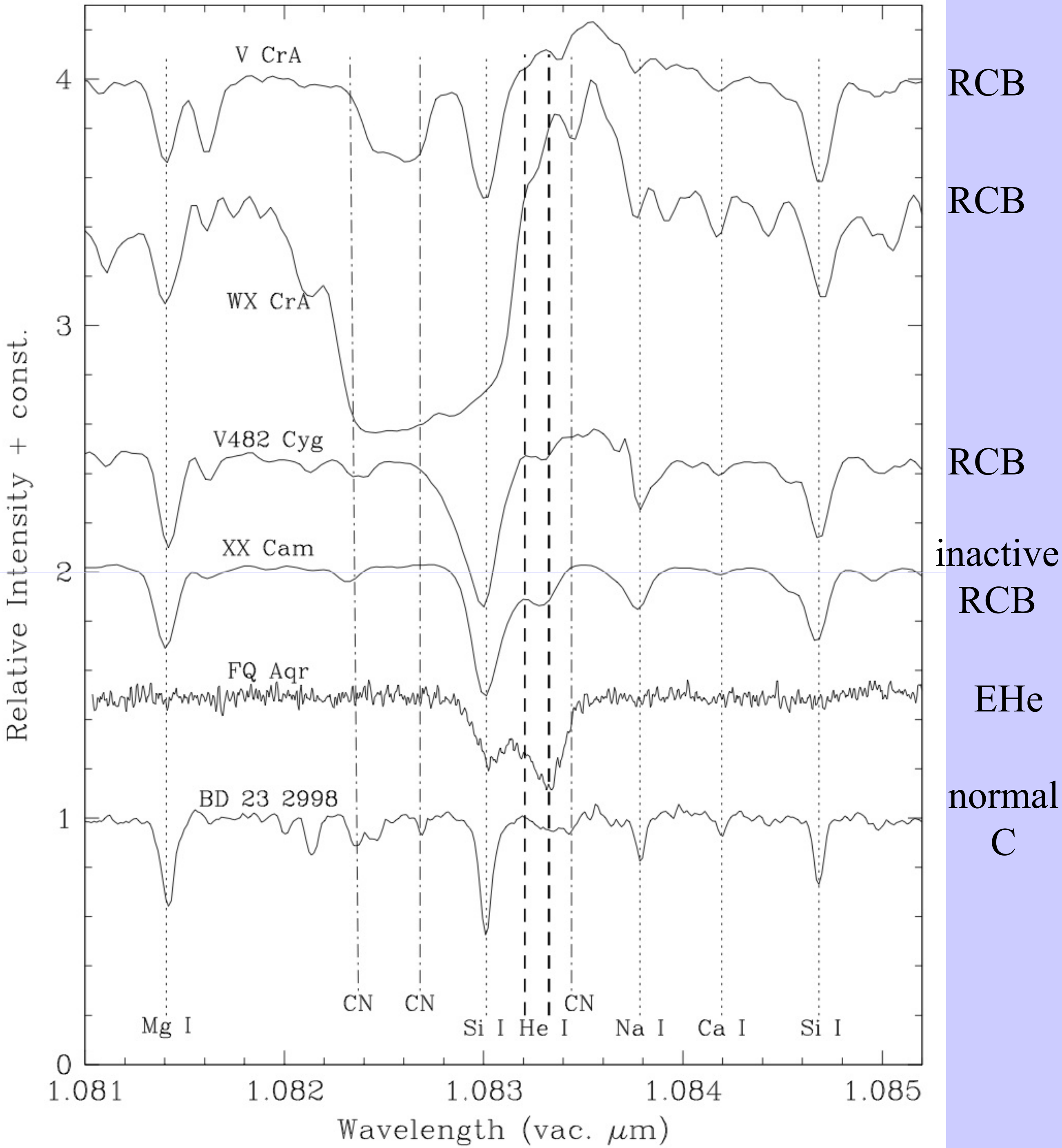
5. It has been suggested that winds in RCB stars are driven by dust. If winds are present in HdC stars then some other wind-driving mechanism than dust must exist.

He 10830 Å spectra of R CrB stars



UKIRT
Clayton et al. 2003

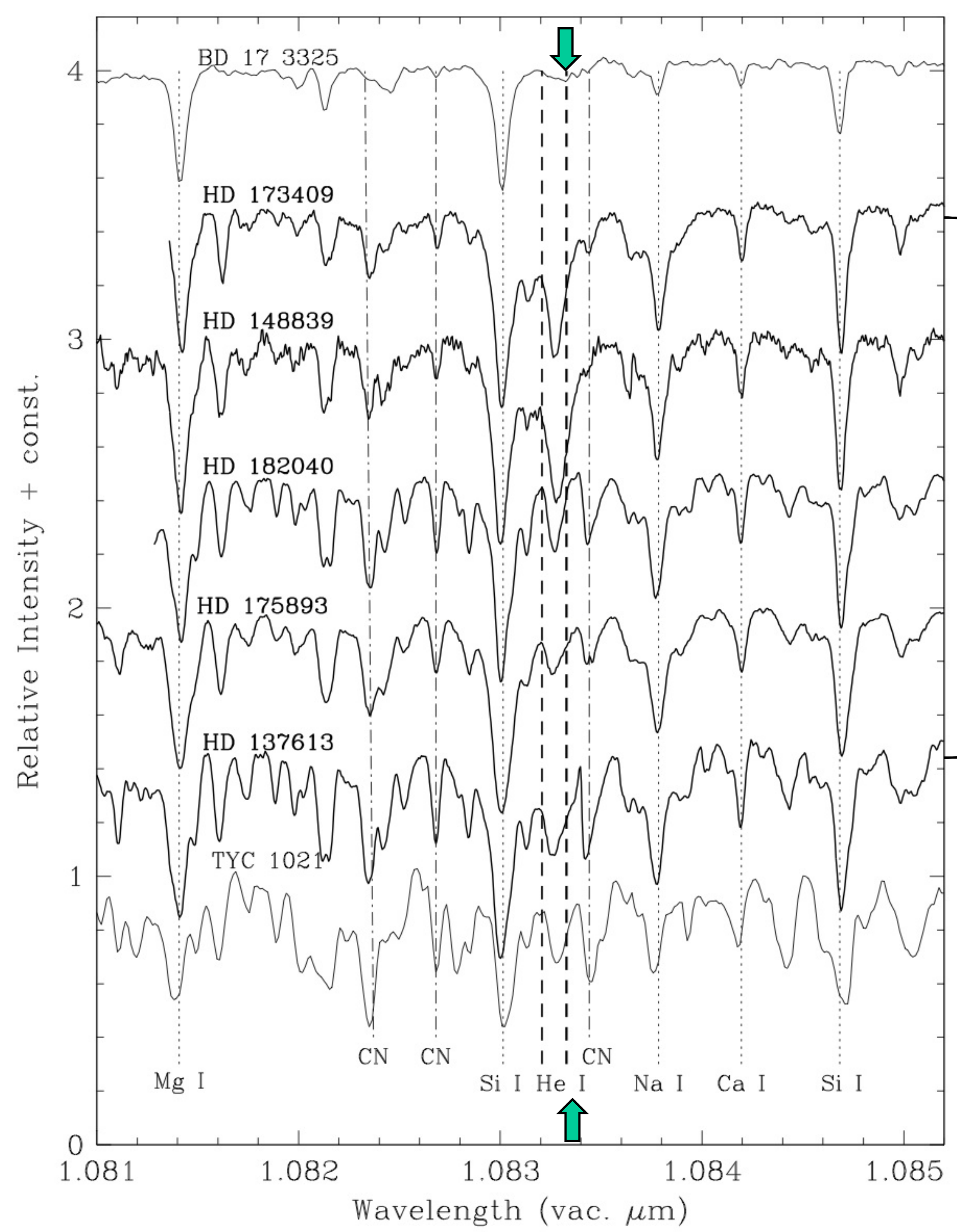
RCB stars and other stars (UKIRT)



Broad 10830Å absorptions
P Cygni profiles

HdC Stars
Gemini S – Phoenix
2008 Feb 4, 7; Apr 4-6

No broad 10830 Å lines

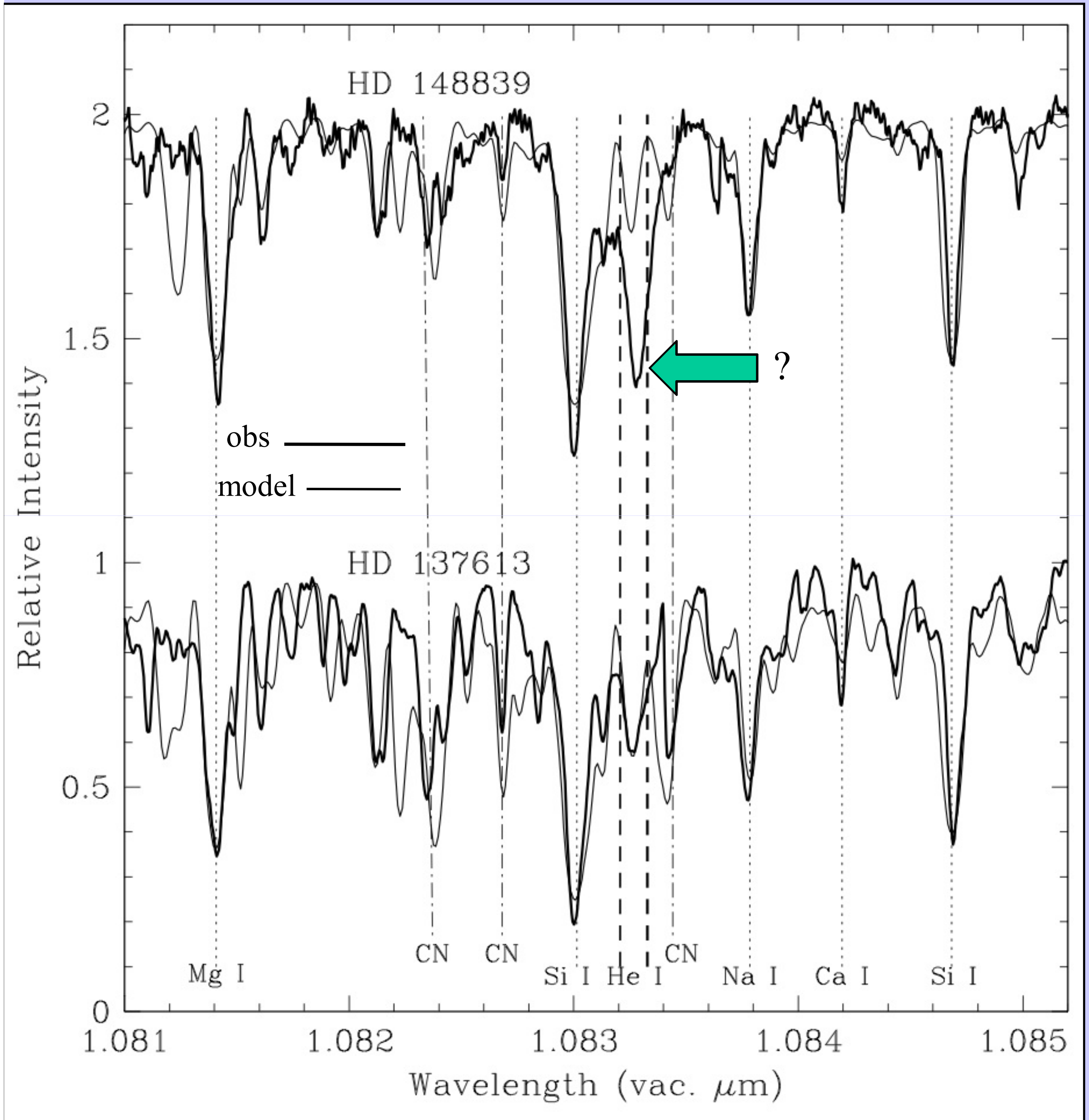


Hot C

HdCs

Cool C

HdC model spectra



Poor fit near the He line, but residual doesn't look like a wind line

Good fit near the He line

Conclusions

- There is no evidence for winds in HdC stars based on spectra of the He 10830 Å line.
- HdC stars do not have winds even remotely approaching the strengths seen in RCB stars.

Questions & Future work

1. What determines whether a wind is present (RCB) or absent (HdC)?

2. Why do HdC stars have more ^{18}O than RCB stars?

3. How does wind relate to ^{16}O /^{18}O?
   (are RCB's and HdC's an evolutionary sequence or do they correspond to different kinds (masses or relative masses) of mergers)?

4. CO spectra of remaining cool RCB stars should be observed.

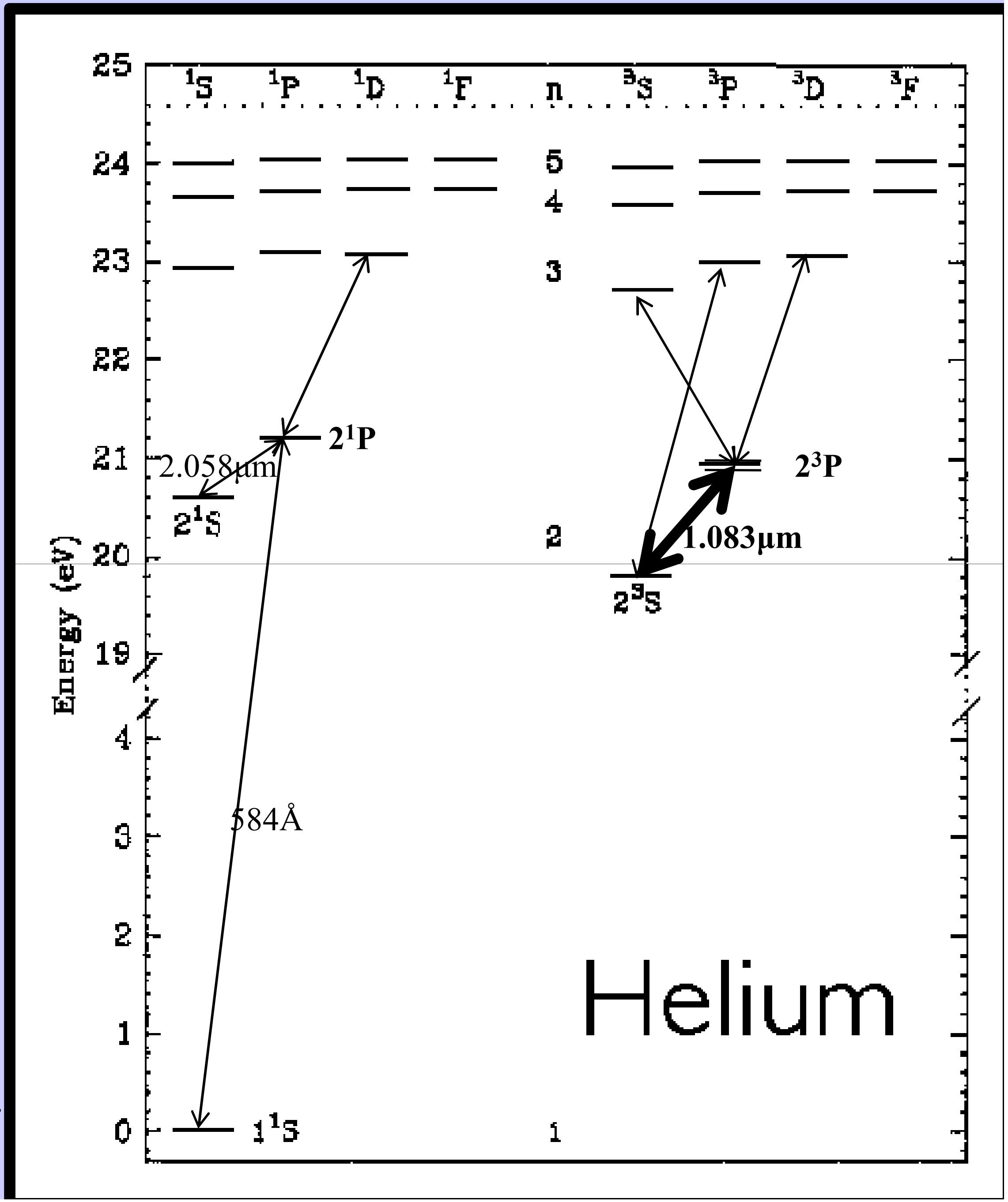
5. More accurate isotopic ratios: higher spectral resolution observations (Phoenix, GNIRS); better model-spectrum fitting (being done by others)

6. Is it possible to identify (and then measure) more HdC stars?

7. More accurate models of WD mergers and the nucleosynthesis associated with them are needed.

The He I 10830Å Line

- $2^3 P_{2,1,0} - 2^3 S_1$ transition
  - both levels ~20eV above ground
- triplet: two closely spaced components at 1.0833217 µm and 1.0833306 µm and a third (weak) component at 1.0832057 µm.
- $2^3 S_1$ is metastable and cannot radiate to ground or be radiatively excited from the (singlet 1S) ground state.
- n=2 levels can be populated from below by collisional excitation (energies >20 eV for the 23 S level) or from above by radiative decay such as would occur following recombination of He II.
- Ionization of He I to He II requires either collisions or photons of energy >24 eV *(unlikely in RCB and HdC stars)*.
- ***Thus, if 10830 is present in absorption in RCB and HdC stars, the 2³S level must be collisionally excited (by high energy - 20eV collisions, which is consistent with- observed broad 10830 absorption profile).***



“Arigato” for your attention.