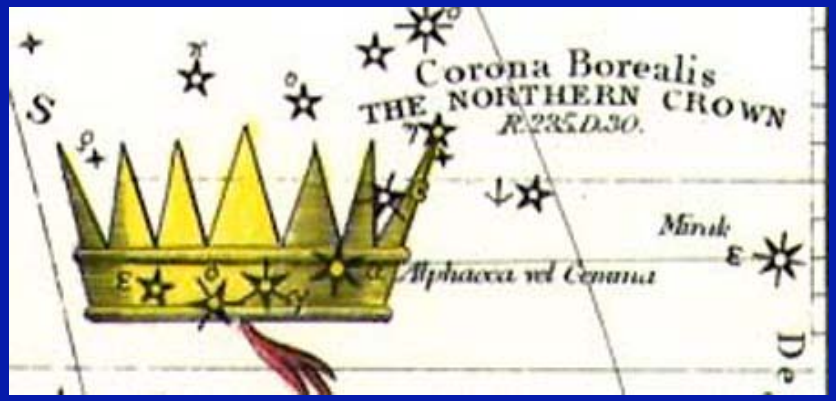
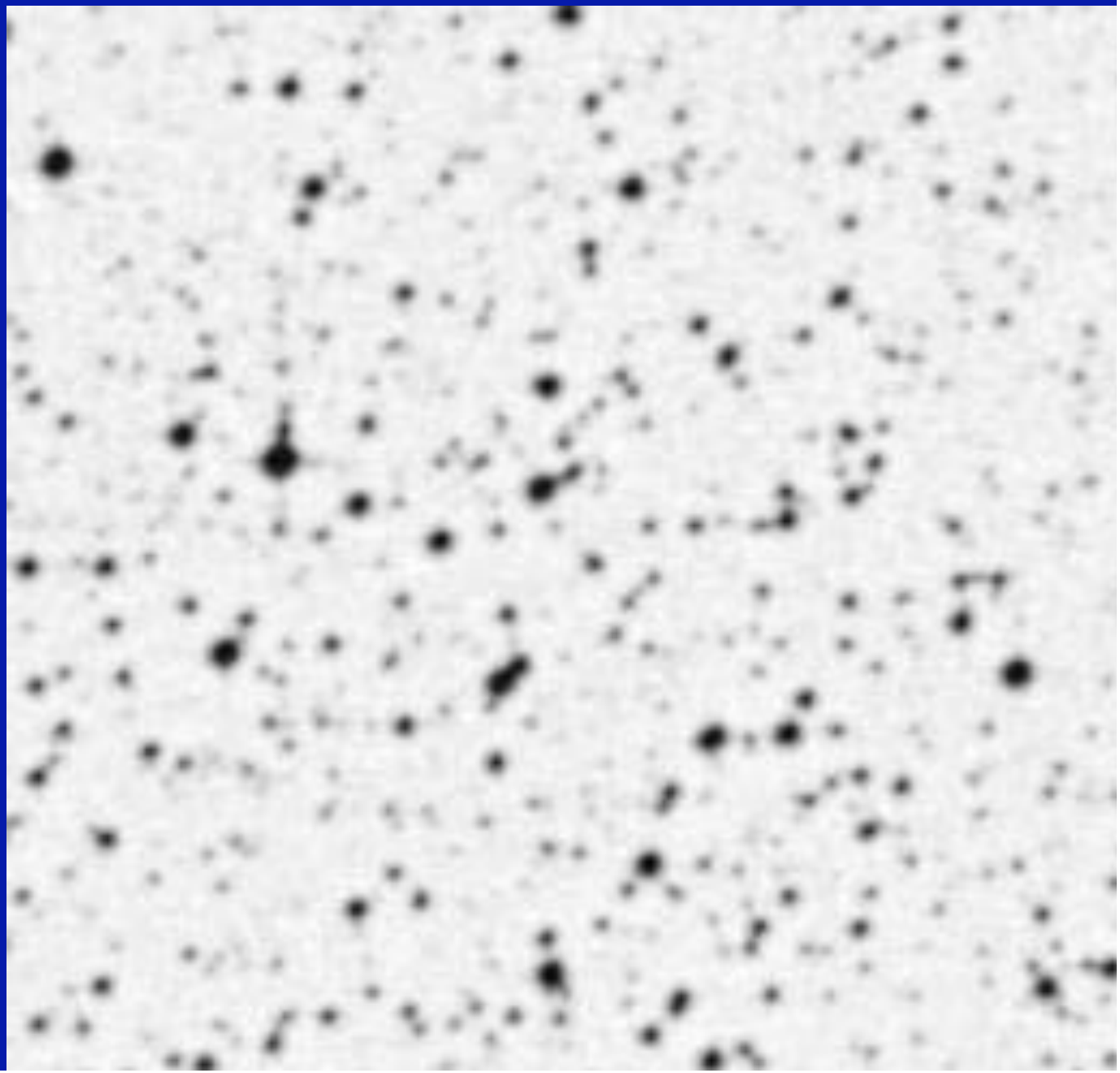
R Coronae Borealis St
Double White Dwarf



Geoffrey C. Clayton



THE ASTROPHYSICAL JOURNAL, 225:212–220, 1978 October 1

TYPE I SUPERNOVAE, R CORONAE BOREALIS STARS, AND THE CRAI

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Received 1977 December 15; accepted 1978 April 6

ABSTRACT

Present observations and theory point to Type I supernovae (SN I) as being old disk helium-rich red supergiants at the time of outburst. There is a class of stars which to these specifications, the hydrogen-deficient carbon (Hd C) stars, the best known which are the *R Coronae Borealis* variables; hence these stars may be SN I progenit present rather large uncertainties the rate of production of Hd C stars is consiste rate of Type I supernovae in the Galaxy. Paczyński's suggestion that R Coronae B are mixed, completely hydrogen-depleted stars of 1–2 $M_\odot$ may call for extended ma lifetimes, which in turn would explain how stars with $M > M_{Ch}$, the Chandrasekha only now evolving to explosive end points in elliptical galaxies.

The Crab Nebula, being helium-rich, metal-poor, and apparently of only moderate also be related to this class of event.

Subject headings: nebulae: Crab Nebula — stars: R Coronae Borealis — stars: stellar statistics — stars: supernovae

I. INTRODUCTION

Type I supernovae (SN I) have long been known to pose a conundrum: they occur in elliptical galaxies implying ages of at least $\sim 10^{10}$ yr. According to the standard theory of single star evolution, stars currently evolving in such galaxies should have $M \lesssim 1\ M_\odot$ and hence die a quiet death. This paper suggests that a class of stars, the hydrogen-deficient carbon (Hd C)

et al. (1973) argued that for the continuum is sufficiently well fit that a radius can be deduced temperature and flux. Somewhat the photospheric radius was ~ Type II (SN II) (Kirshner *et al.* Kwan 1974, 1975). Kirshner, Arp determined that the photospheric

THE ASTROPHYSICAL JOURNAL, 277:355–360, 1984 February 1

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

R. F. WEBBINK
Department of Astronomy, University of Illinois
Received 1983 June 13; accepted 1983 July 27

ABSTRACT

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

Subject headings: stars: R Coronae Borealis — stars: supernovae — stars: white dwarfs

I. INTRODUCTION

Type I supernovae (SN I) differ strikingly from those of Type II (SN II) not only in the regularity of their outburst

and the accretion rate (Taam 1980; W Taam 1980; Fujimoto and Taam 198 see Wheeler 1982 for a review). These varying degrees of success in producin

eriodical Changes of Brightness of two fixed Stars.

d Pigott, *Esq.* *Communicated by* *Sir* Henry C.
, *Bart. F.R.S.*

Read January 12, 1797.

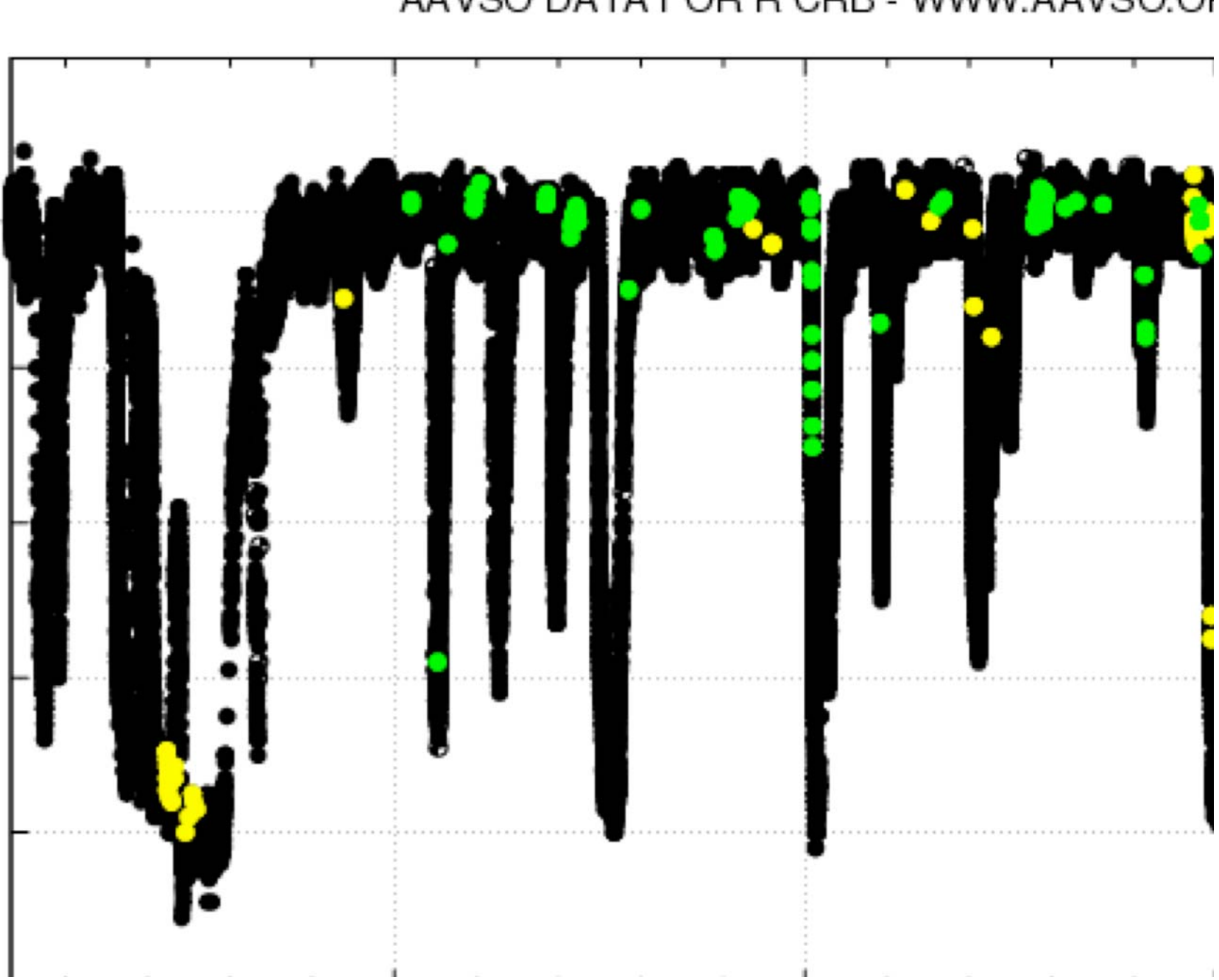
Bath, August, 1796.

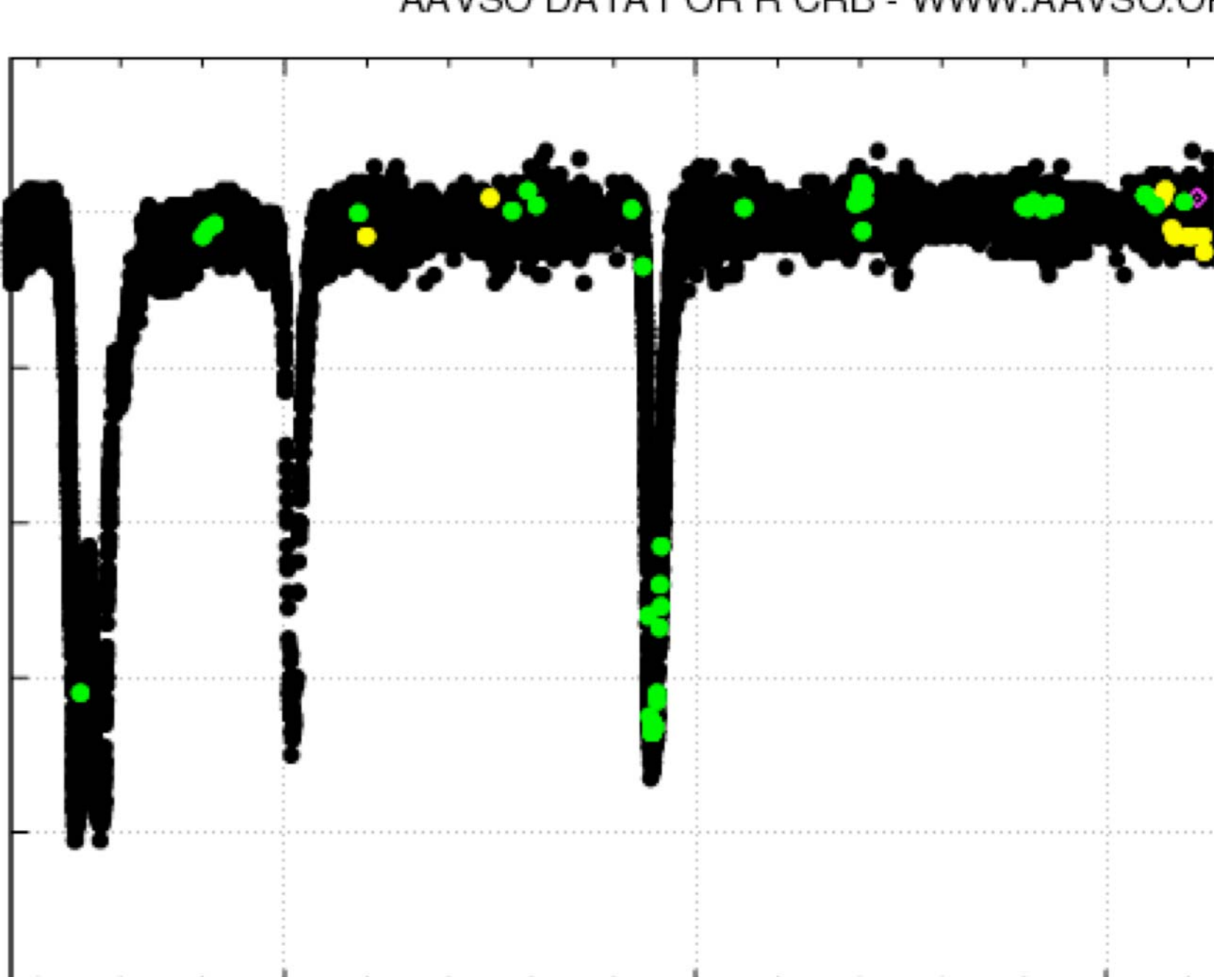
those far distant suns, the fixed stars, have baffled
tion with regard to our knowledge of their dis-
itudes, and attractions; we have, nevertheless, by
their periodical changes of light, established a
ity between them and our sun; and among such
vable number, we may expect to find some with
tation much longer and shorter than those we are
ainted with, and with changes perhaps even suf-
d to afford a ready means for determining accu-
ences of terrestrial longitudes. This would be a
ctory, useful, and profitable discovery, and may be
se who have but a slight knowledge of astronomy,
t with great exactness, and a good memory, a con-
ut be given. The discoveries which at present I
our of laying before the Society are the periodical

Pigott & Englefield 1797, Ph
of the Royal Society of Lond

Extracts from my Journal, of th
in the *Northern Cro*

Dates.		Magnit.	
1783. July	27	7.8	seen with difficulty w
	30	7	much brighter.
	31	7	though the air was ha
August	8	7	saw it distinctly—op
1784. July	11	6.7	thought it conside rather less than π,
	14	6.7	not so bright as ϱ, eq
1785. May	20	7	it is marked less tha
1795. May	28	.	not visible with an o
June	20	9.10	evidently less than o
	23	9	equal to, or brighter
	29	8.9	evidently brighter th
July	6		
	7	7	evidently brighter th
	13		
	24		
	25	6.7	certainly brighter tha
	31		
August	2		
	6		
	11	6.7	nearly equal to π; n
	17		
	21		
	28	7.6	less than π; moon n
Sept.	4	7	evidently less than π
	6		
	13	8.7	evidently less than π
	15	9	less than o, and equa
	16	9.10	equal to, or less than
	20		not visible with an


AAVSO DATA FOR R CRB - WWW.AAVSO.O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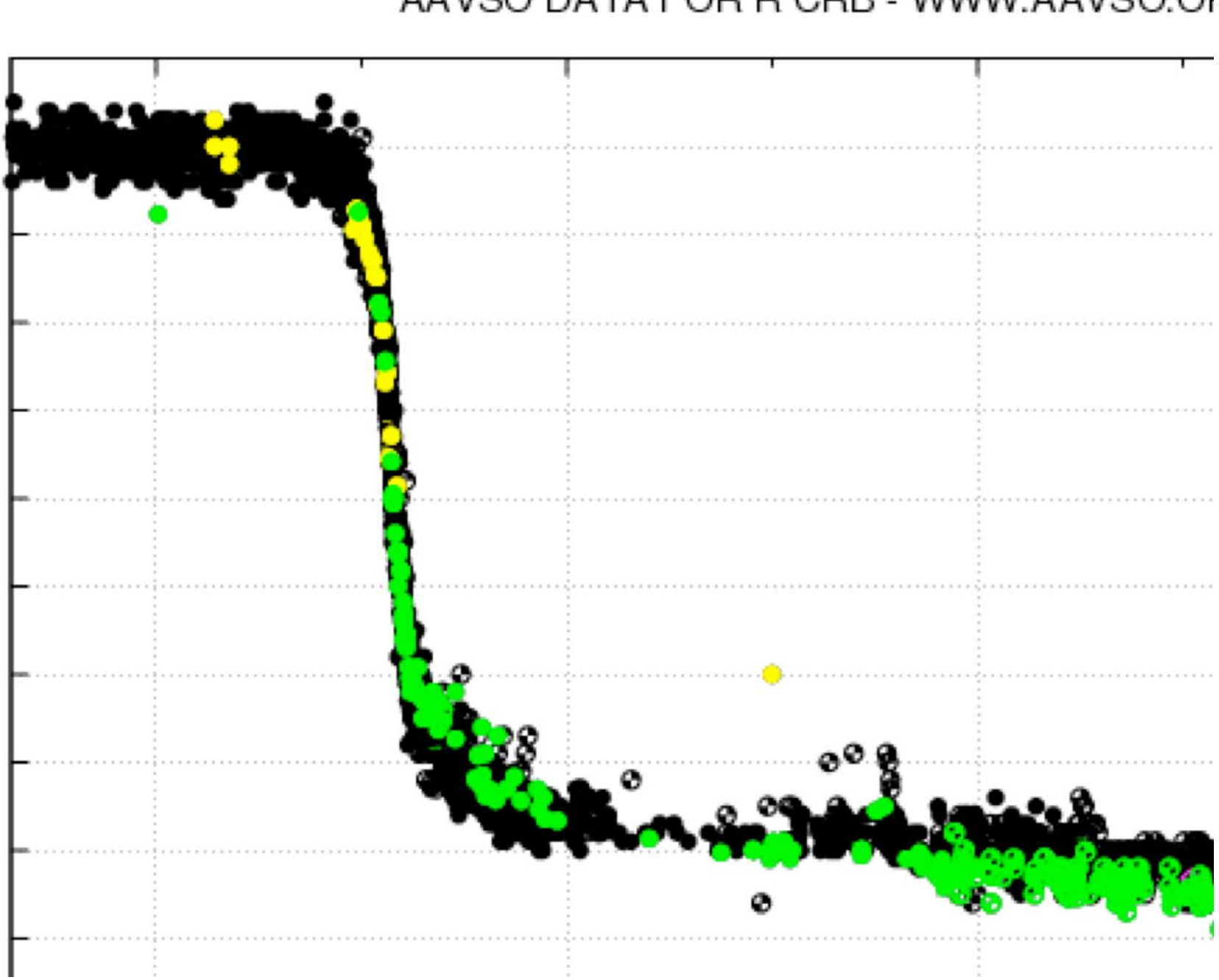
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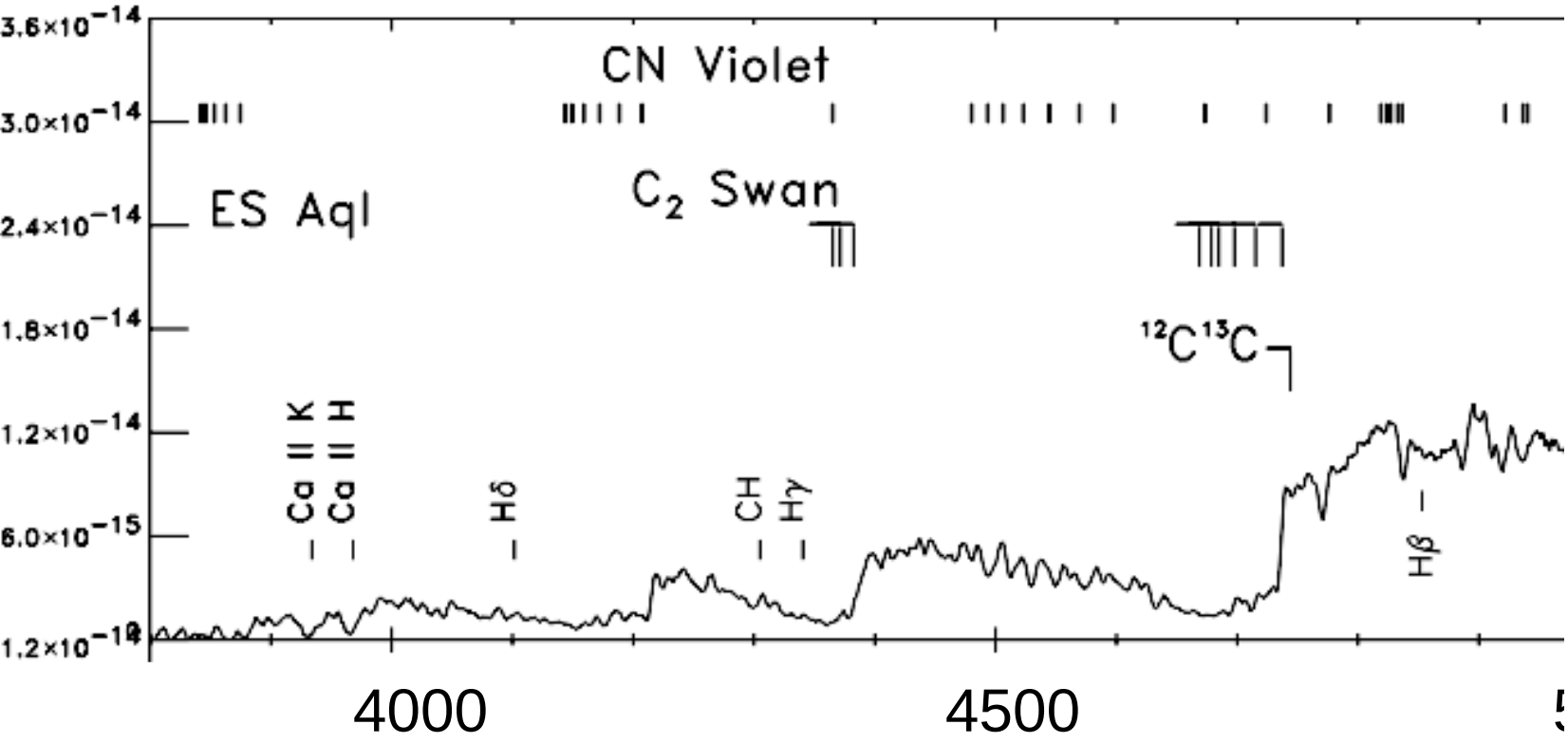
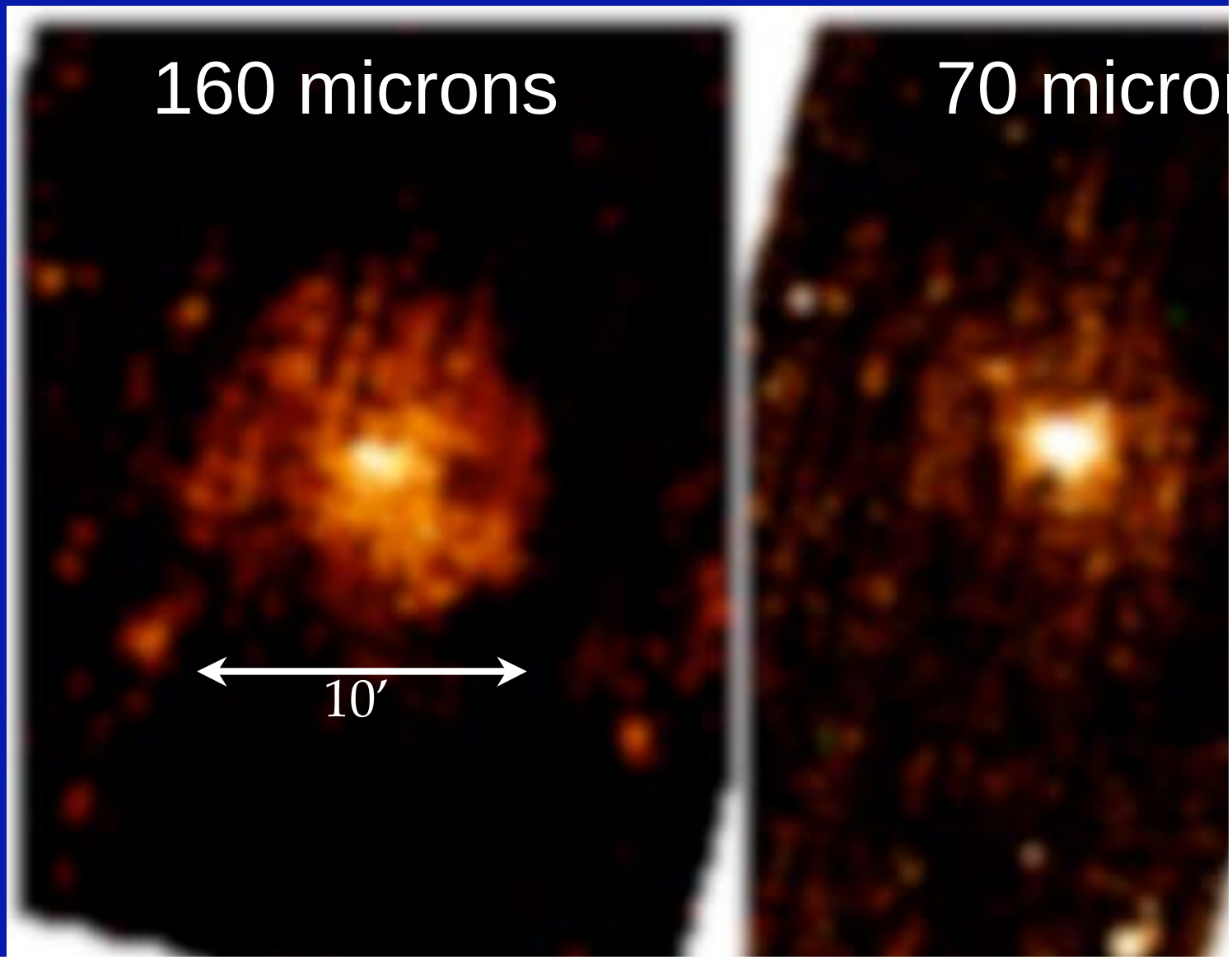
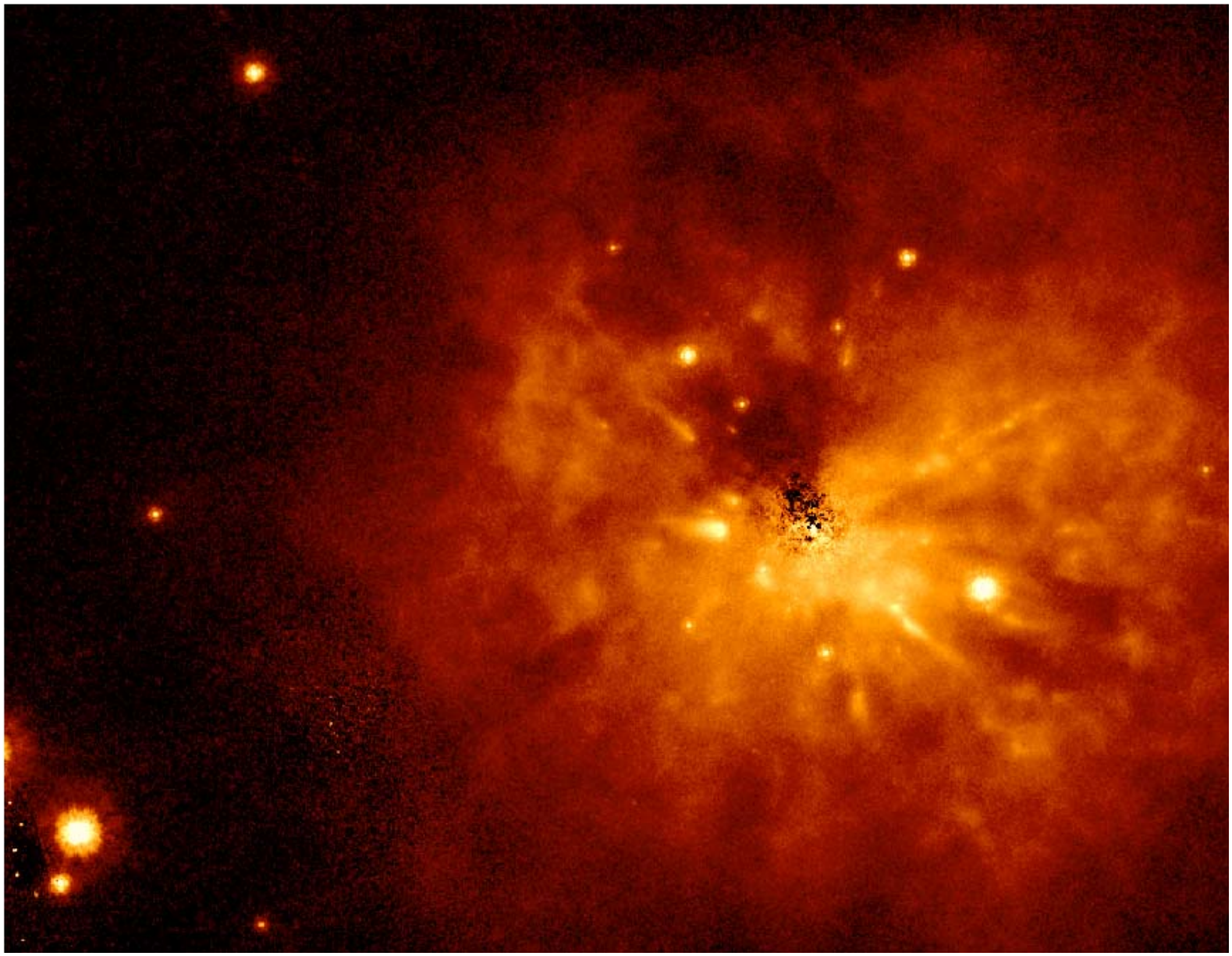

3.6×10⁻¹⁴
3.0×10⁻¹⁴
2.4×10⁻¹⁴
1.8×10⁻¹⁴
1.2×10⁻¹⁴
6.0×10⁻¹⁵
CN Violet
ES Aql
C₂ Swan
¹²C¹³C
Ca II K
Ca II H
Hδ
CH
Hγ
Hβ
4000
4500

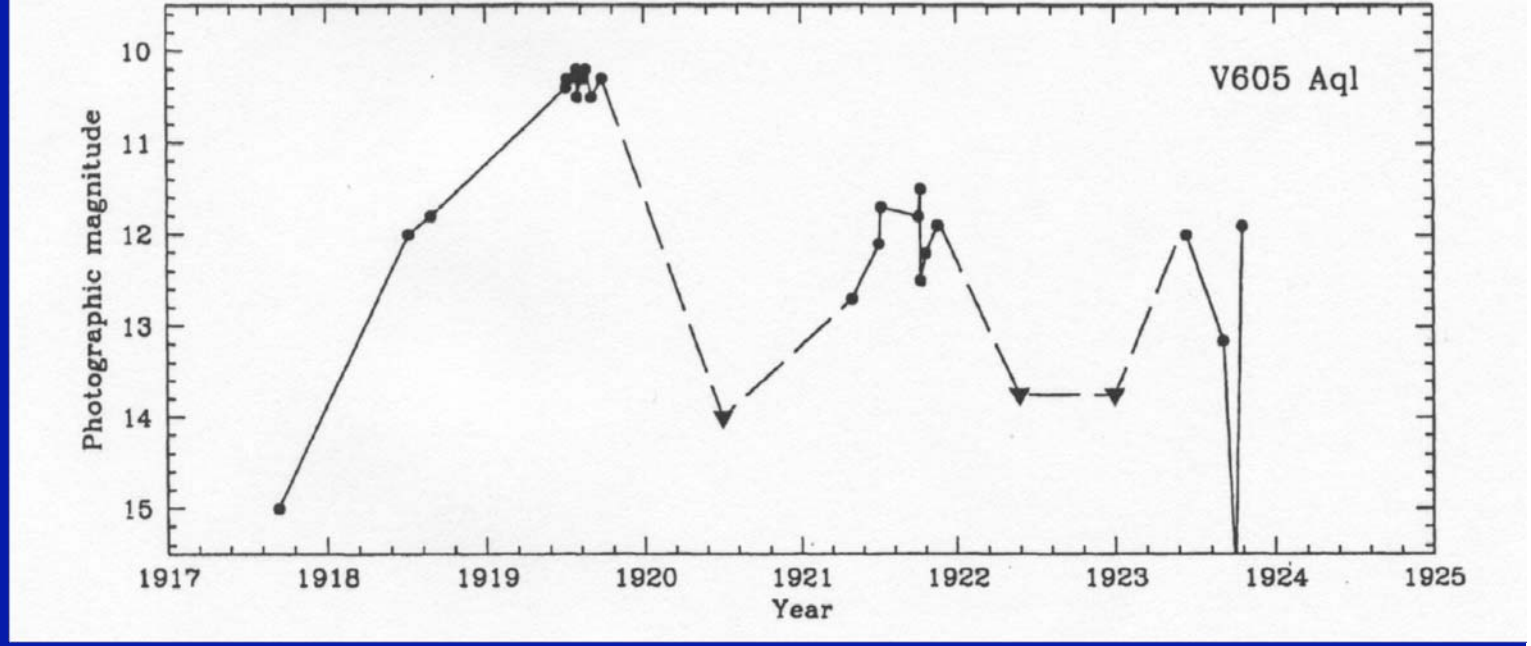

160 microns
70 micro
10′

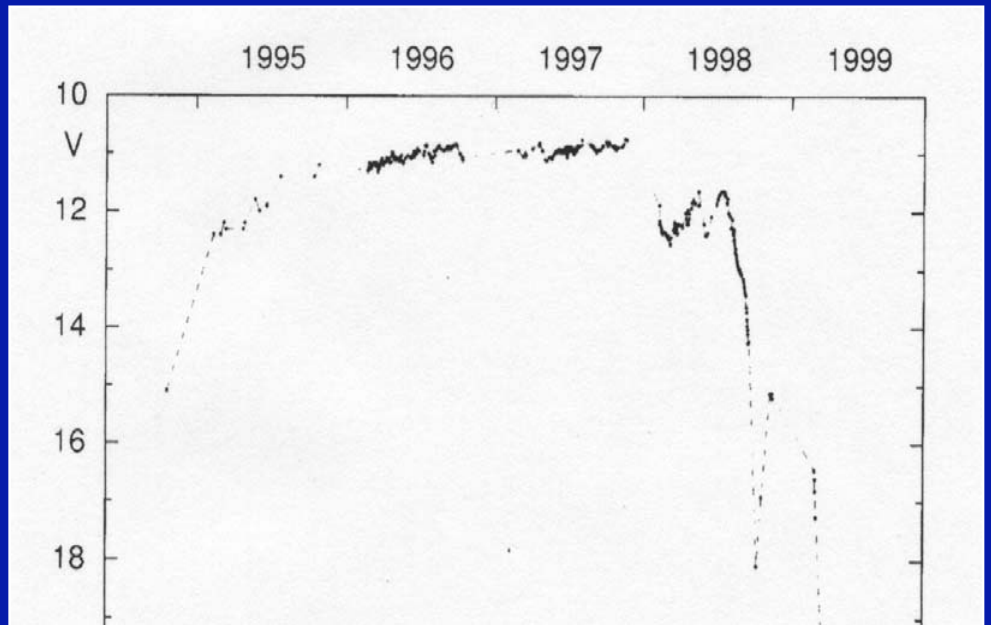


R Coronae Borealis

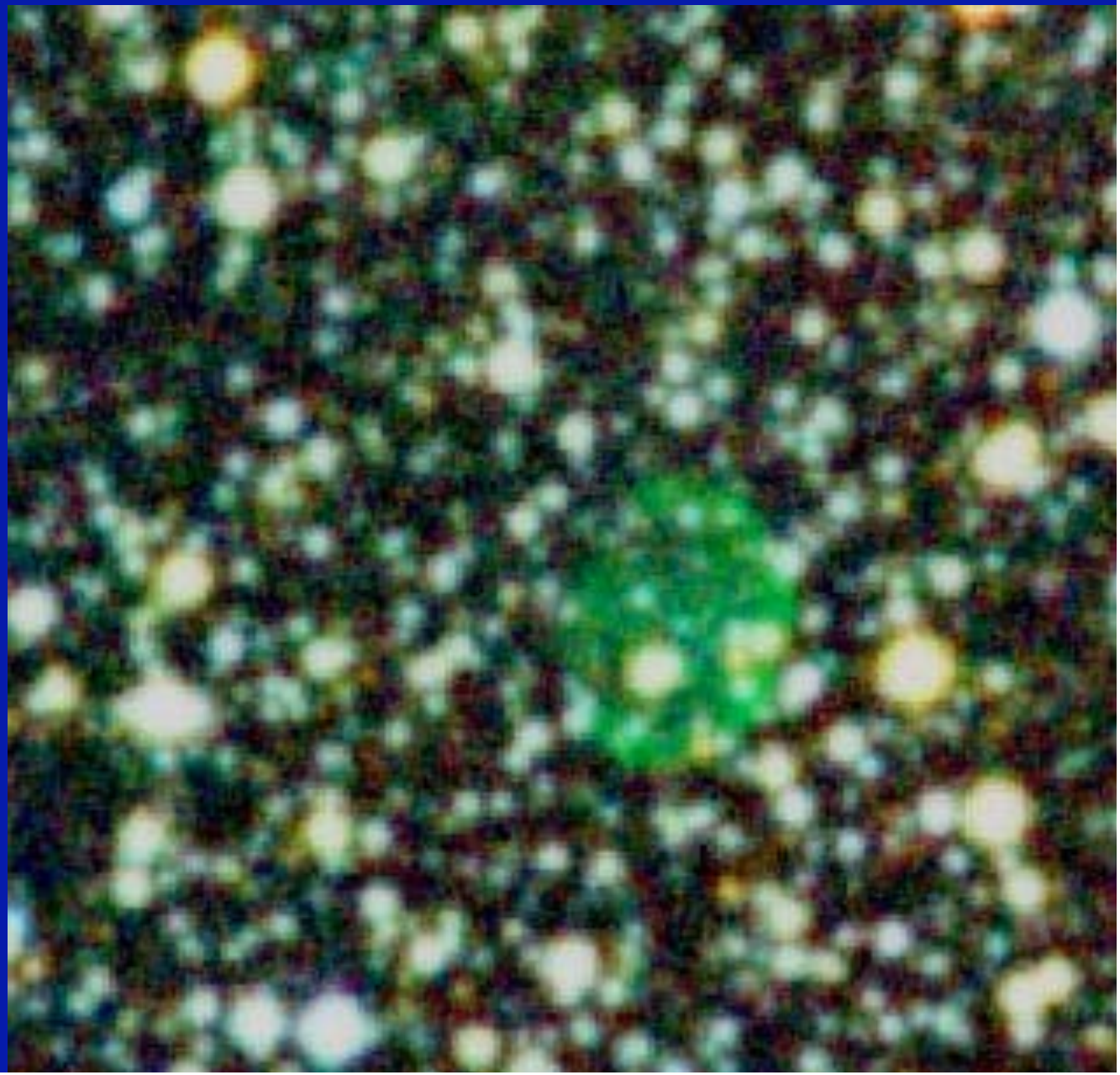
- R CrB discovered to be variable in 1795
- About 55 RCB stars known in MW, 25 in Magellanic
- F or G-Type Supergiants (M_V = -3 to -5)
- 98% He, 1% C, 0% H
- Pulsating variables → Mass ~ 0.8-0.9 M_o
- Large declines (~8 mag) caused by carbon dust
- None are known to be binaries
- Rare Examples of Stellar Evolution:

  Final Helium Shell Flash or Double Degenerate Merg

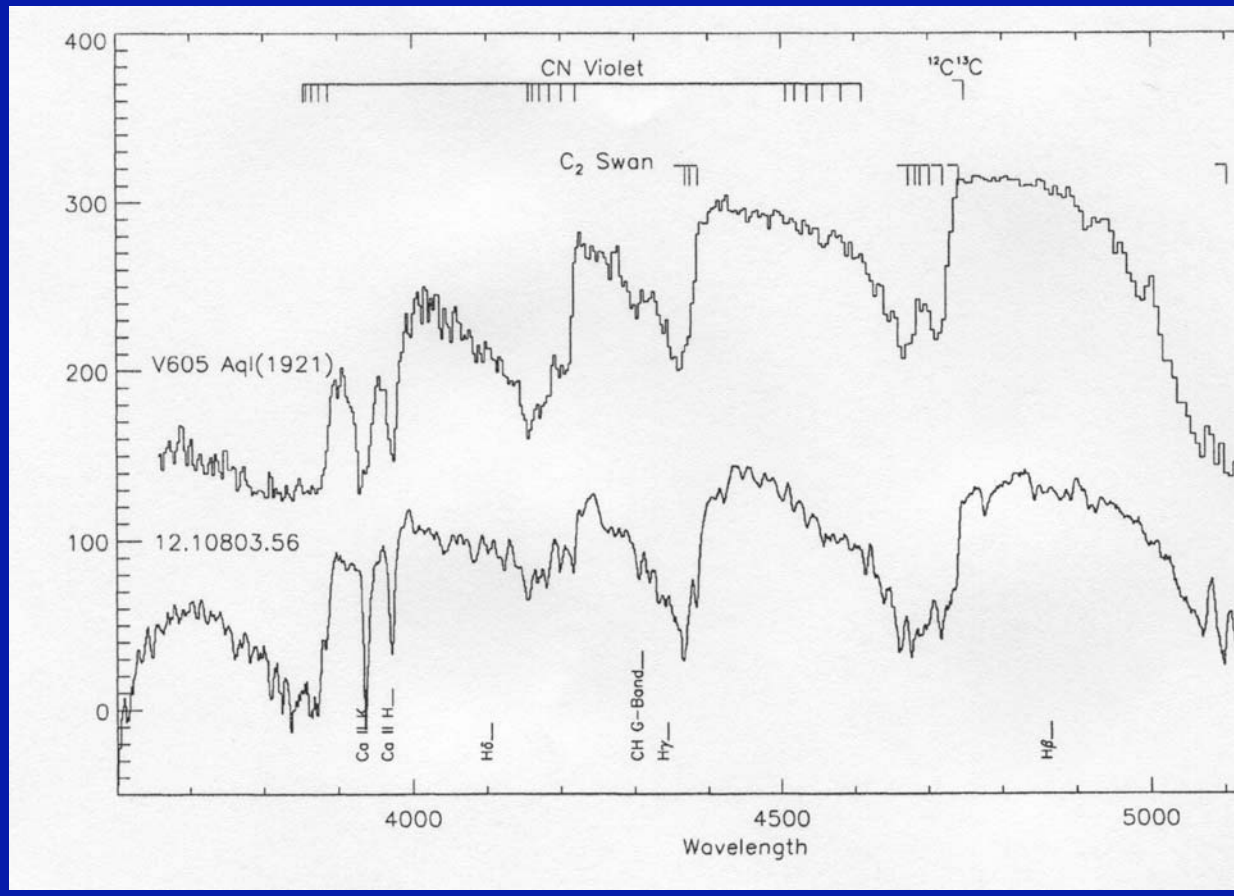

V605 Aql
Photographic magnitude
10
11
12
13
14
15
1917
1918
1919
1920
1921
1922
1923
1924
1925
Year

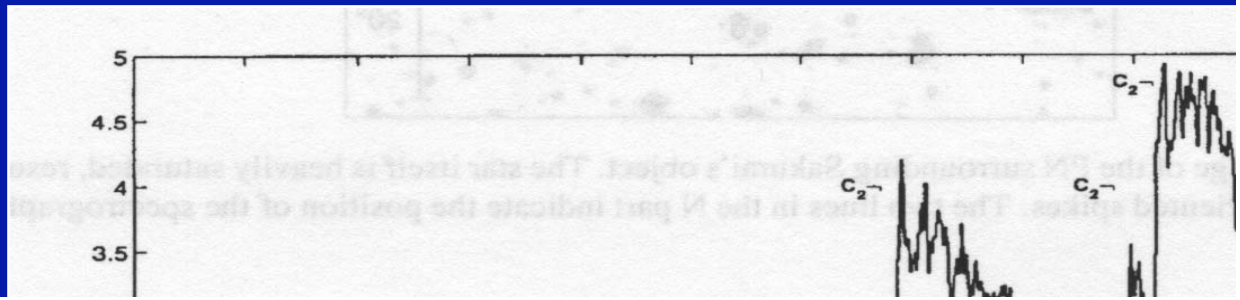

1995
1996
1997
1998
1999
V
10
12
14
16
18

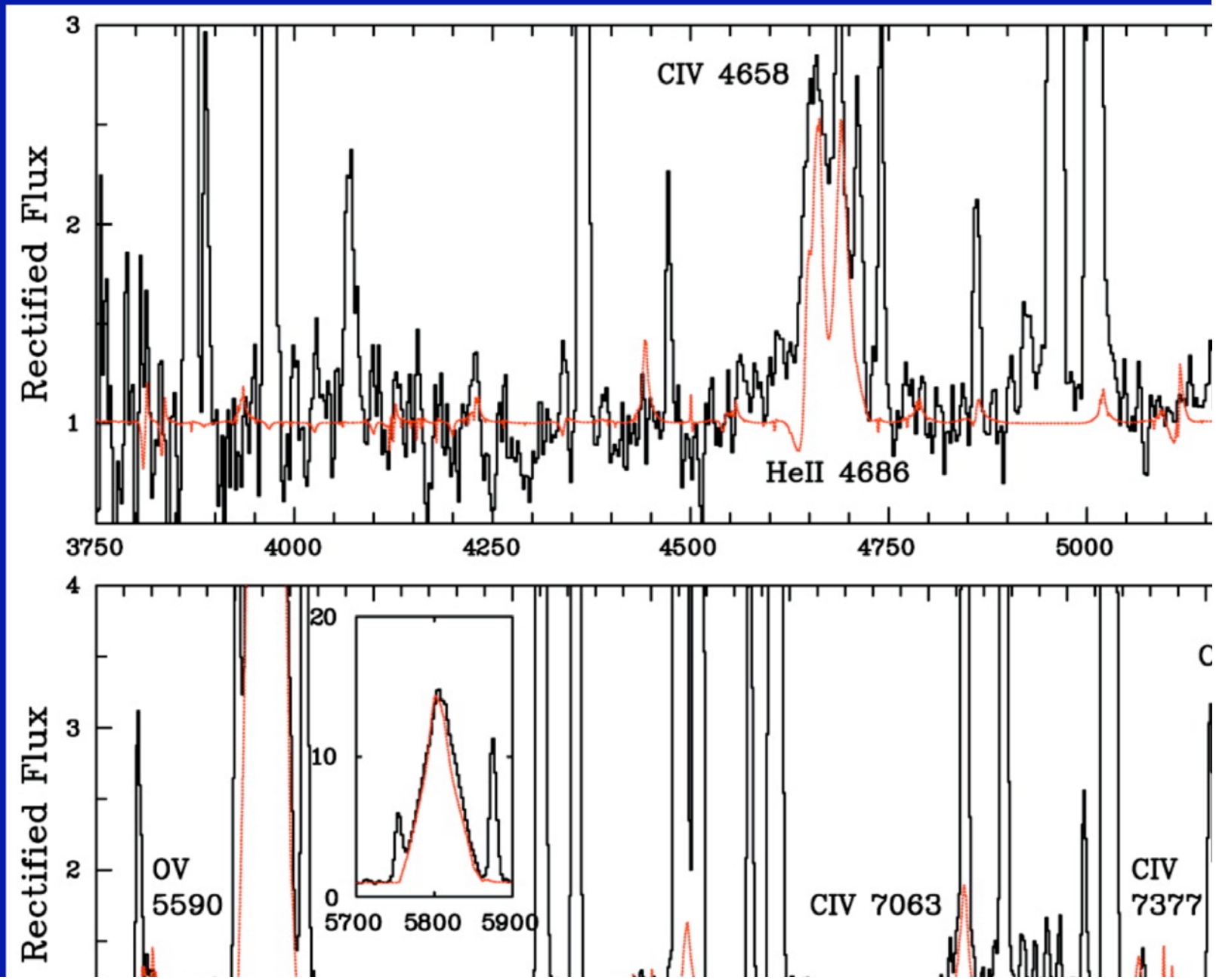
Sak

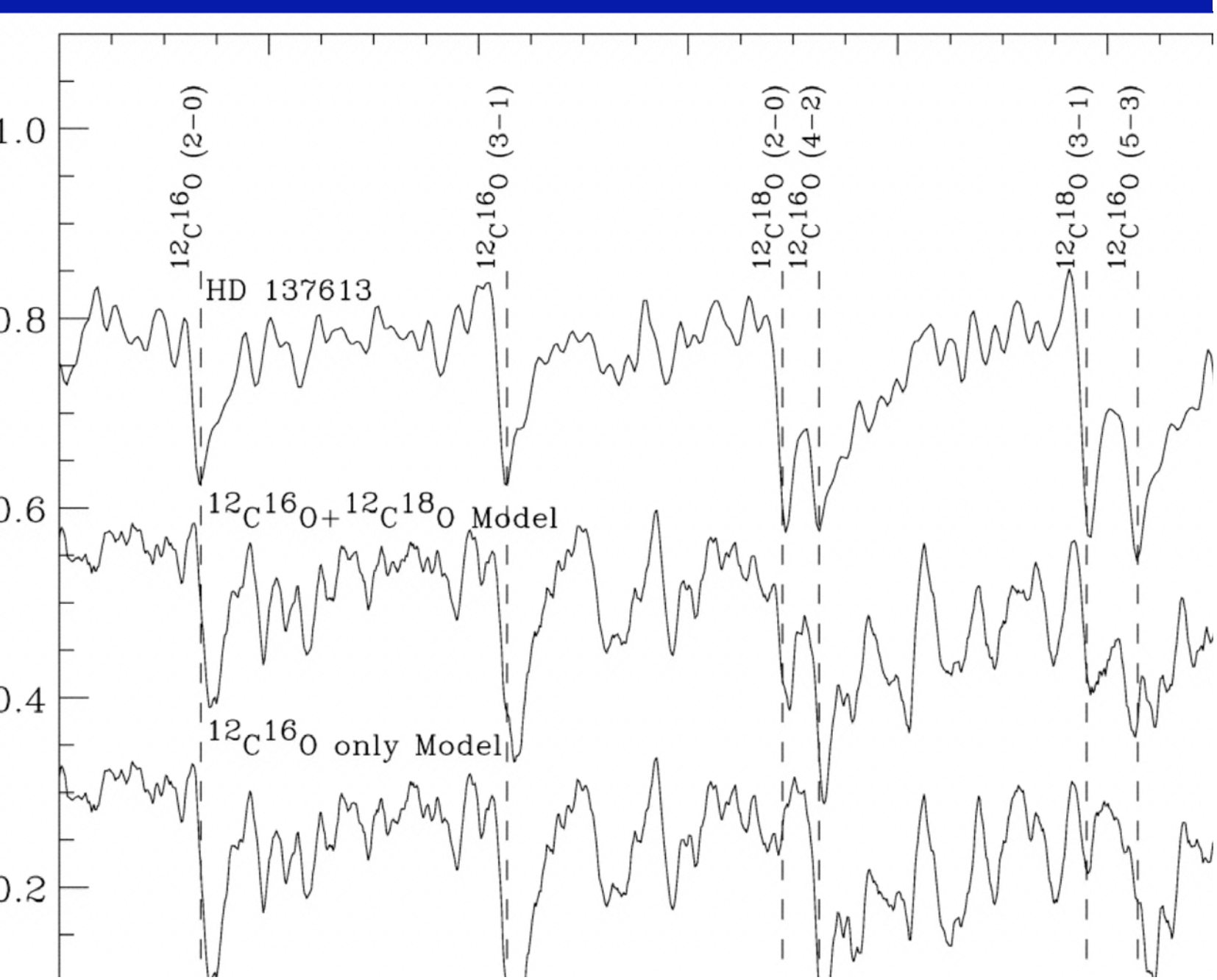


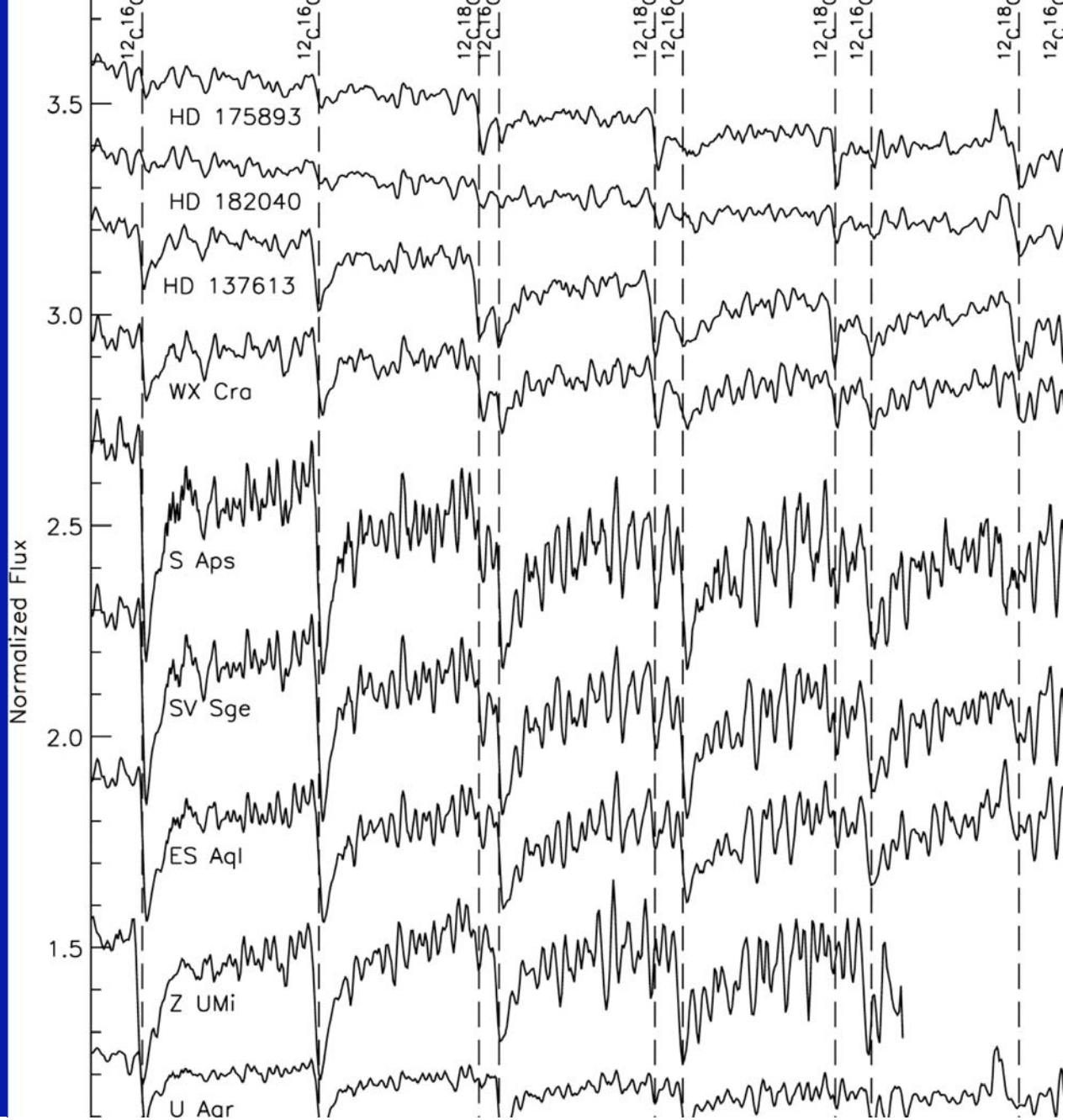
05 Aql
1921)

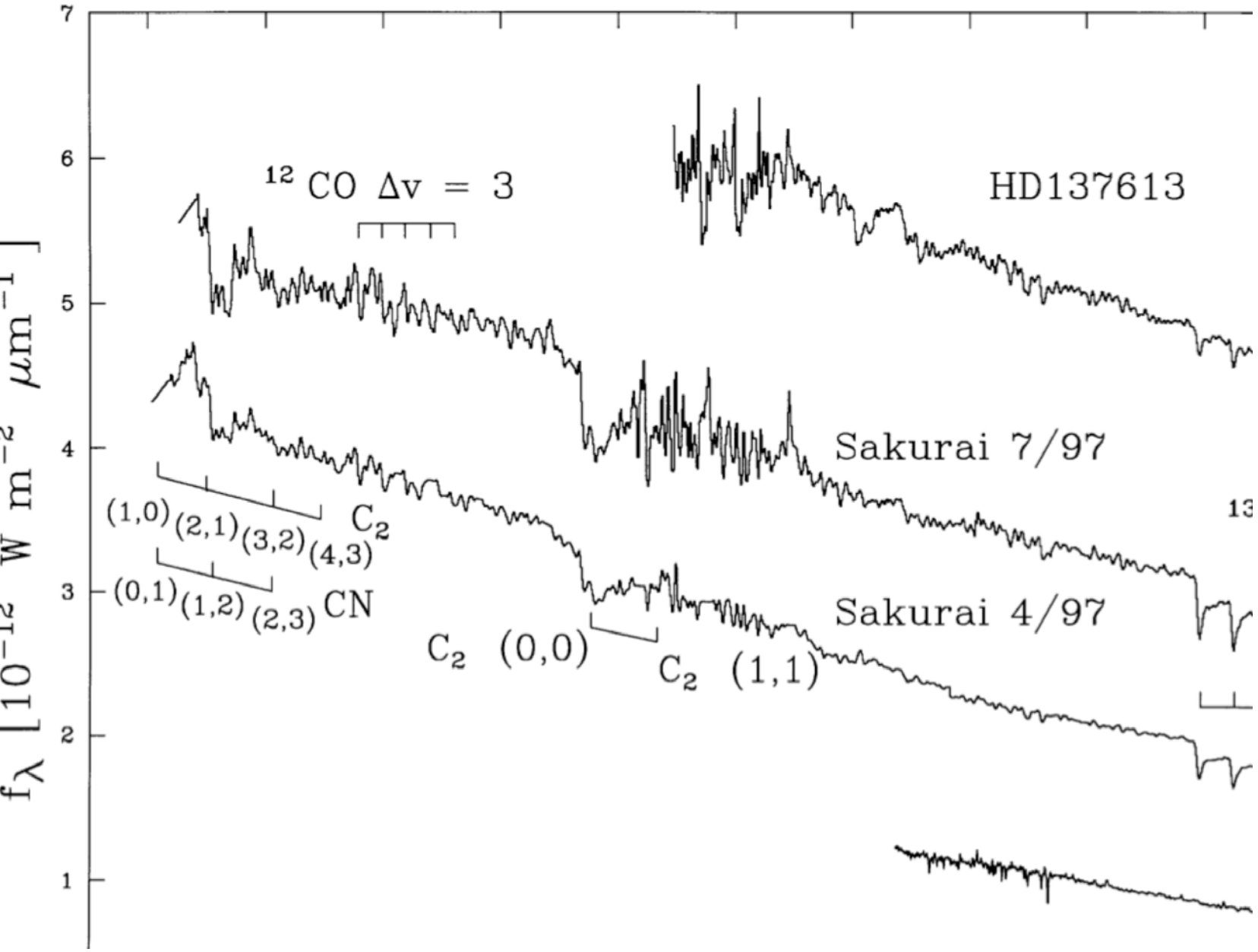

CN Violet
$^{12}C^{13}C$
C_2 Swan
V605 Aql(1921)
12.10803.56
Ca II K
Ca II H
Hδ
CH G-Band
Hγ
Hβ
400
300
200
100
0
4000
4500
5000
Wavelength

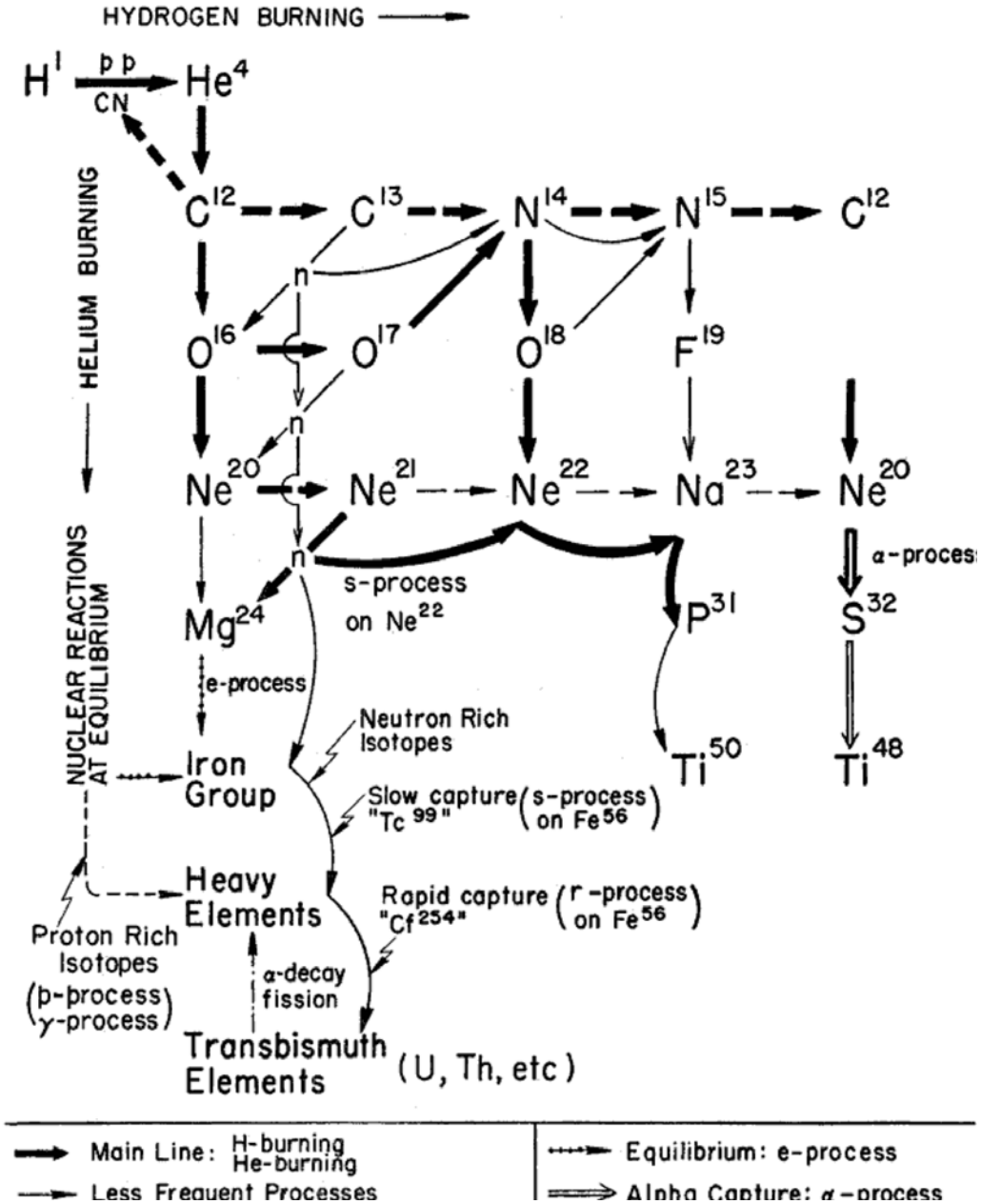

5
4.5
4
3.5
C_2
C_2
C_2

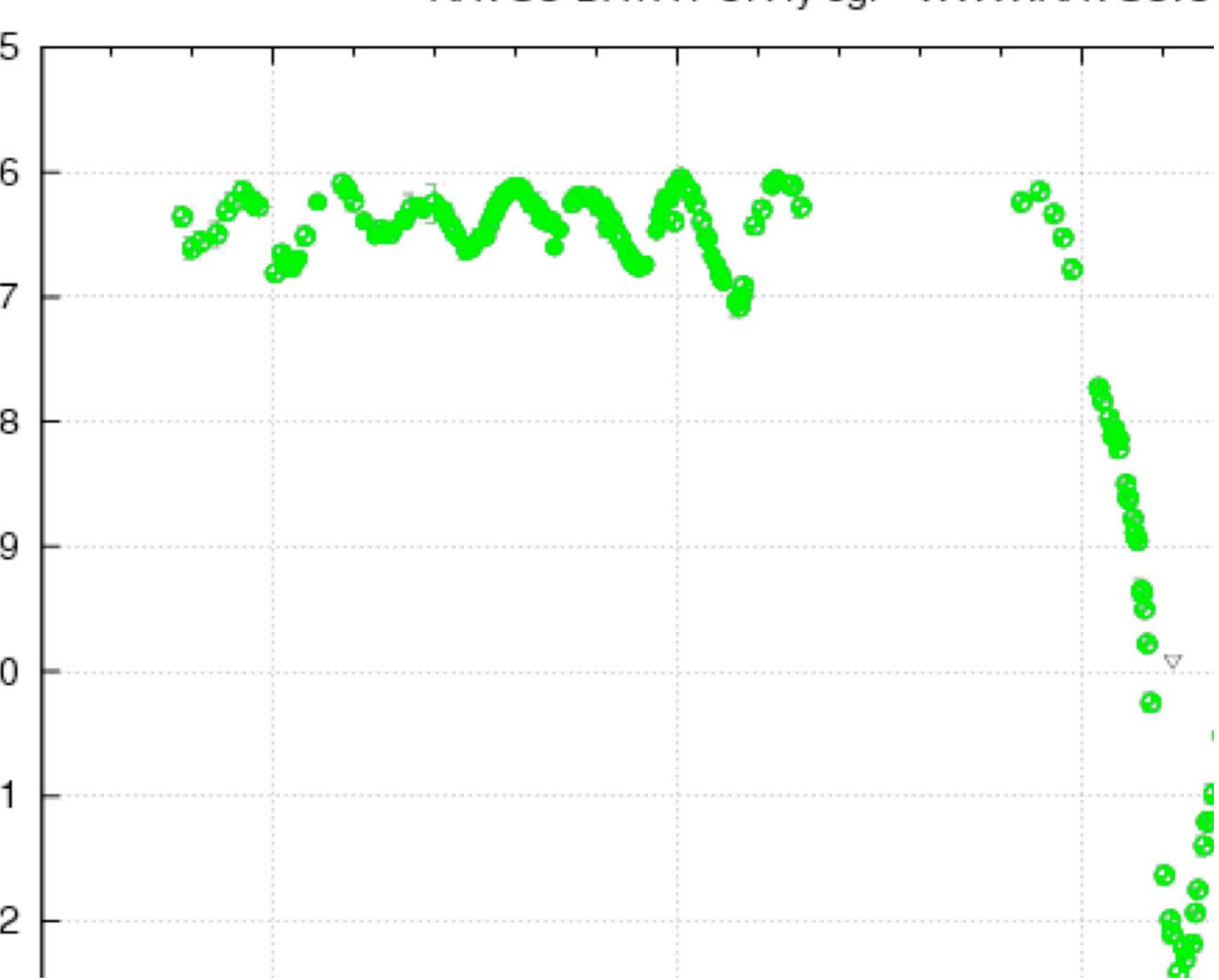

Rectified Flux
CIV 4658
HeII 4686
3750
4000
4250
4500
4750
5000
OV
5590
CIV 7063
CIV
7377
5700
5800
5900

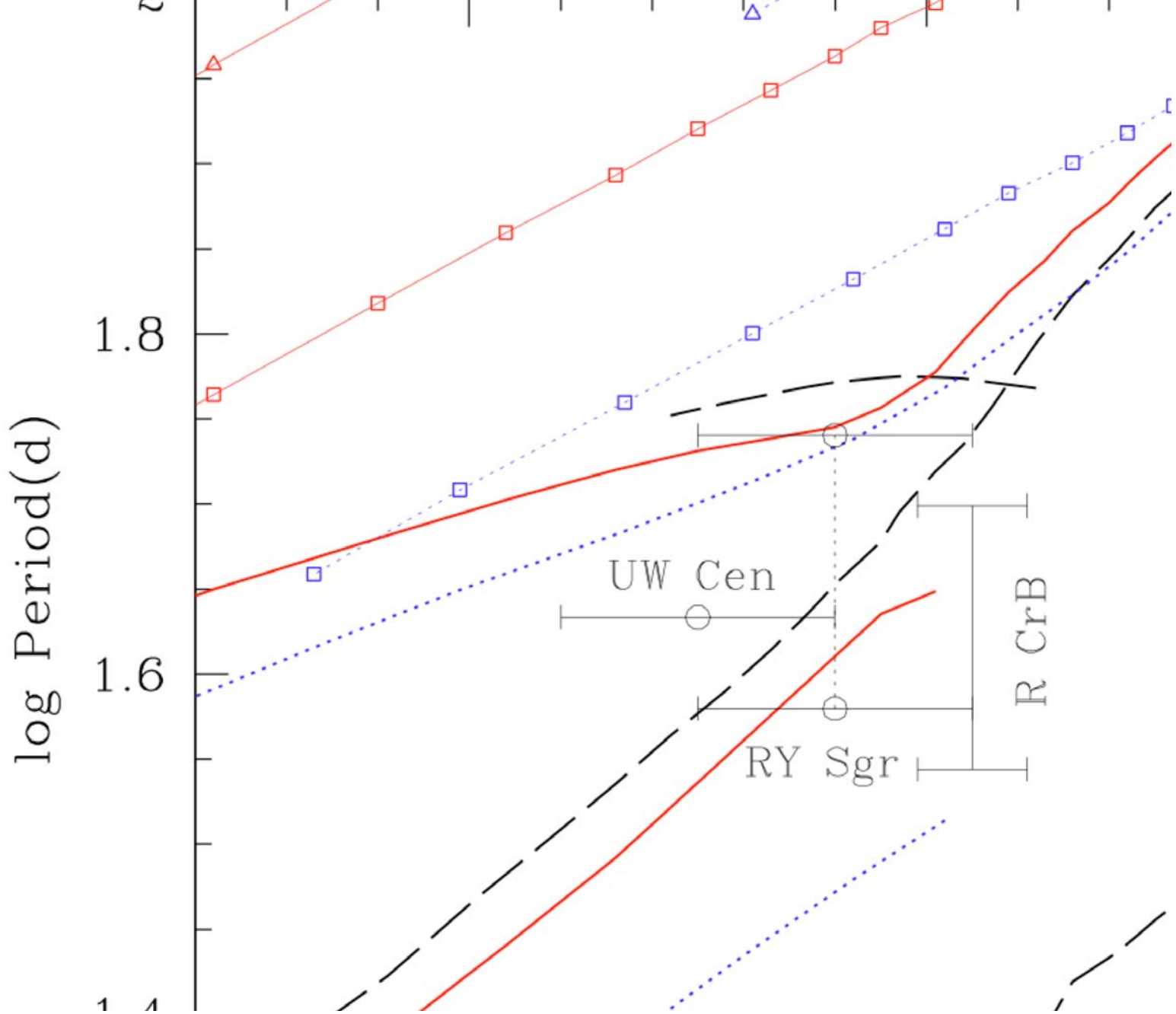

1.0
0.8
0.6
0.4
0.2
$^{12}C^{16}O$ (2–0)
$^{12}C^{16}O$ (3–1)
$^{12}C^{18}O$ (2–0)
$^{12}C^{16}O$ (4–2)
$^{12}C^{18}O$ (3–1)
$^{12}C^{16}O$ (5–3)
HD 137613
$^{12}C^{16}O$+$^{12}C^{18}O$ Model
$^{12}C^{16}O$ only Model

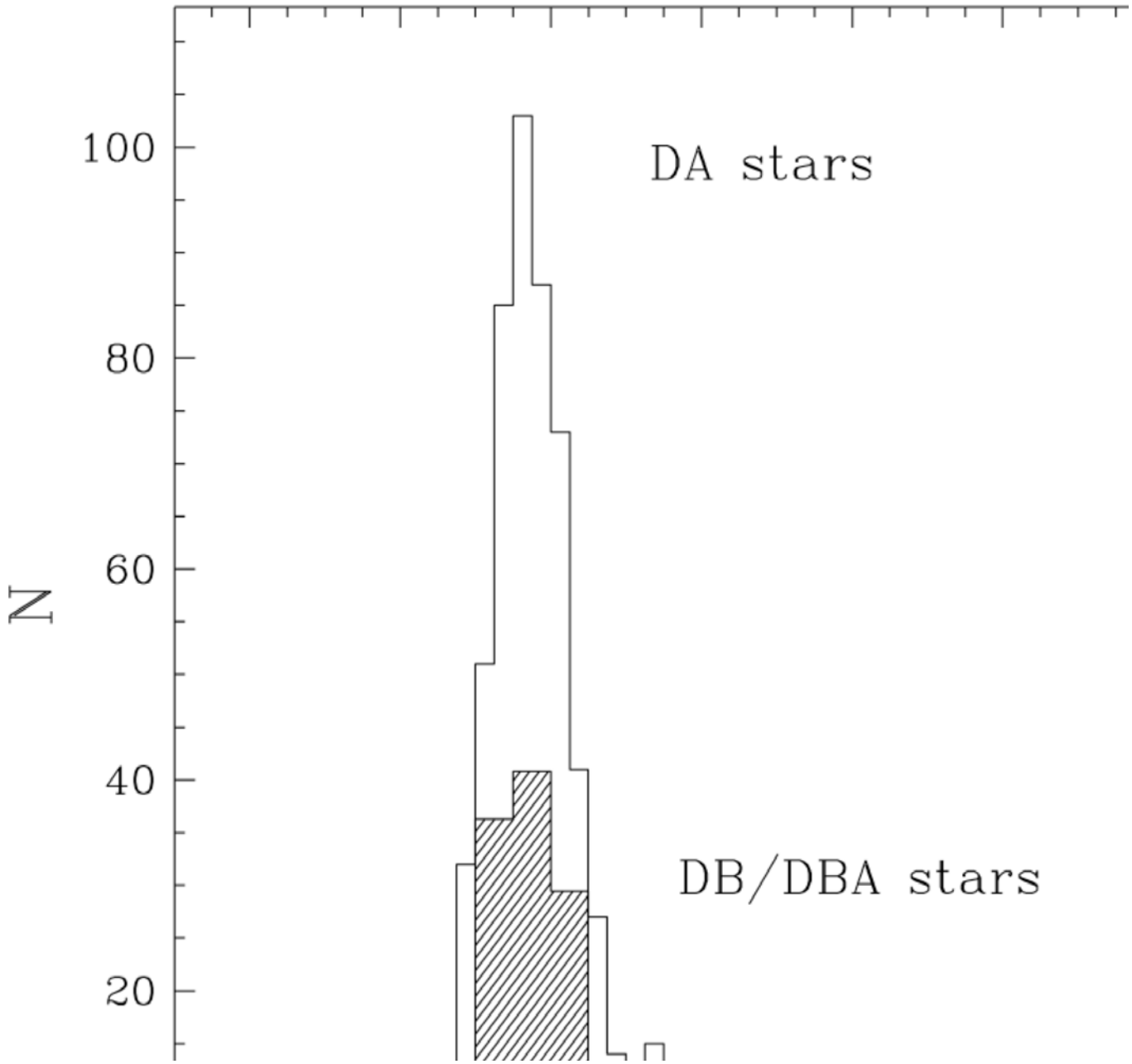

Normalized Flux
3.5
3.0
2.5
2.0
1.5
HD 175893
HD 182040
HD 137613
WX Cra
S Aps
SV Sge
ES Aql
Z UMi
U Aqr

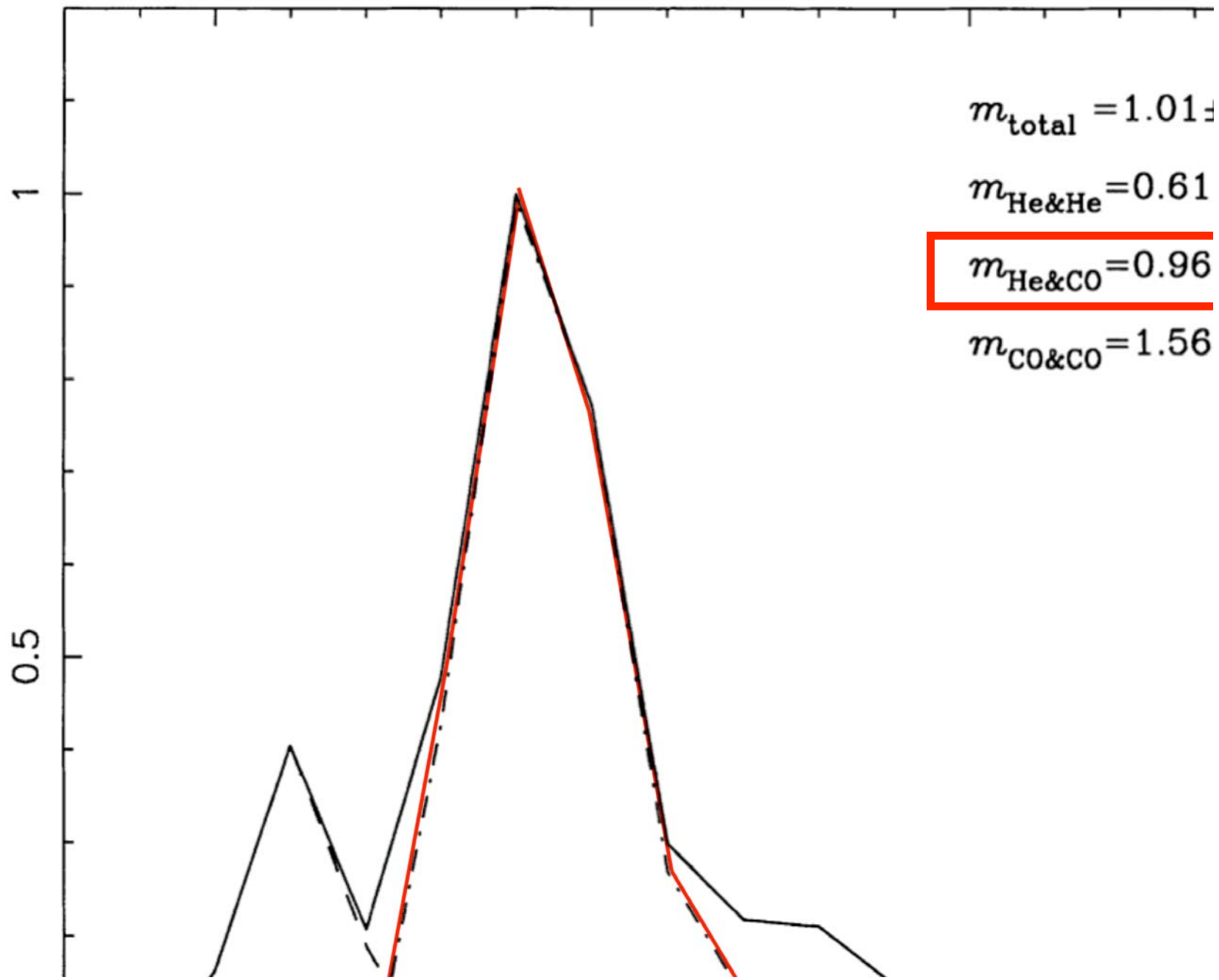

f_λ [10^{-12} W m^{-2} μm^{-1}]
7
6
5
4
3
2
1
^{12}CO Δv = 3
HD137613
Sakurai 7/97
Sakurai 4/97
(1,0) (2,1) (3,2) (4,3) C$_2$
(0,1) (1,2) (2,3) CN
C$_2$ (0,0)
C$_2$ (1,1)


HYDROGEN BURNING
H1
p p
CN
He4
HELIUM BURNING
C12
C13
N14
N15
C12
n
O16
O17
O18
F19
n
Ne20
Ne21
Ne22
Na23
Ne20
n
α-proces
s-process
on Ne22
NUCLEAR REACTIONS
AT EQUILIBRIUM
Mg24
P31
S32
e-process
Neutron Rich
Isotopes
Iron
Group
Ti50
Ti48
Slow capture
"Tc 99"
(s-process
on Fe56)
Heavy
Elements
Rapid capture
"Cf 254"
(r -process
on Fe56)
Proton Rich
Isotopes
(p-process
γ-process)
α-decay
fission
Transbismuth
Elements
(U, Th, etc)
Main Line: H-burning
He-burning
Less Frequent Processes
Equilibrium: e-process
Alpha Capture: α-process


5
6
7
8
9
0
1
2


log Period(d)
1.8
1.6
UW Cen
R CrB
RY Sgr


100
80
60
40
20
N
DA stars
DB/DBA stars


1
0.5
m_{total} =1.01±
$m_{\text{He\&He}}$=0.61
$m_{\text{He\&CO}}$=0.96
$m_{\text{CO\&CO}}$=1.56

rB > 200 yr old

RCB stars known in MW. (Increasing by ~

ulation in LMC => ~3000 RCB stars in MW

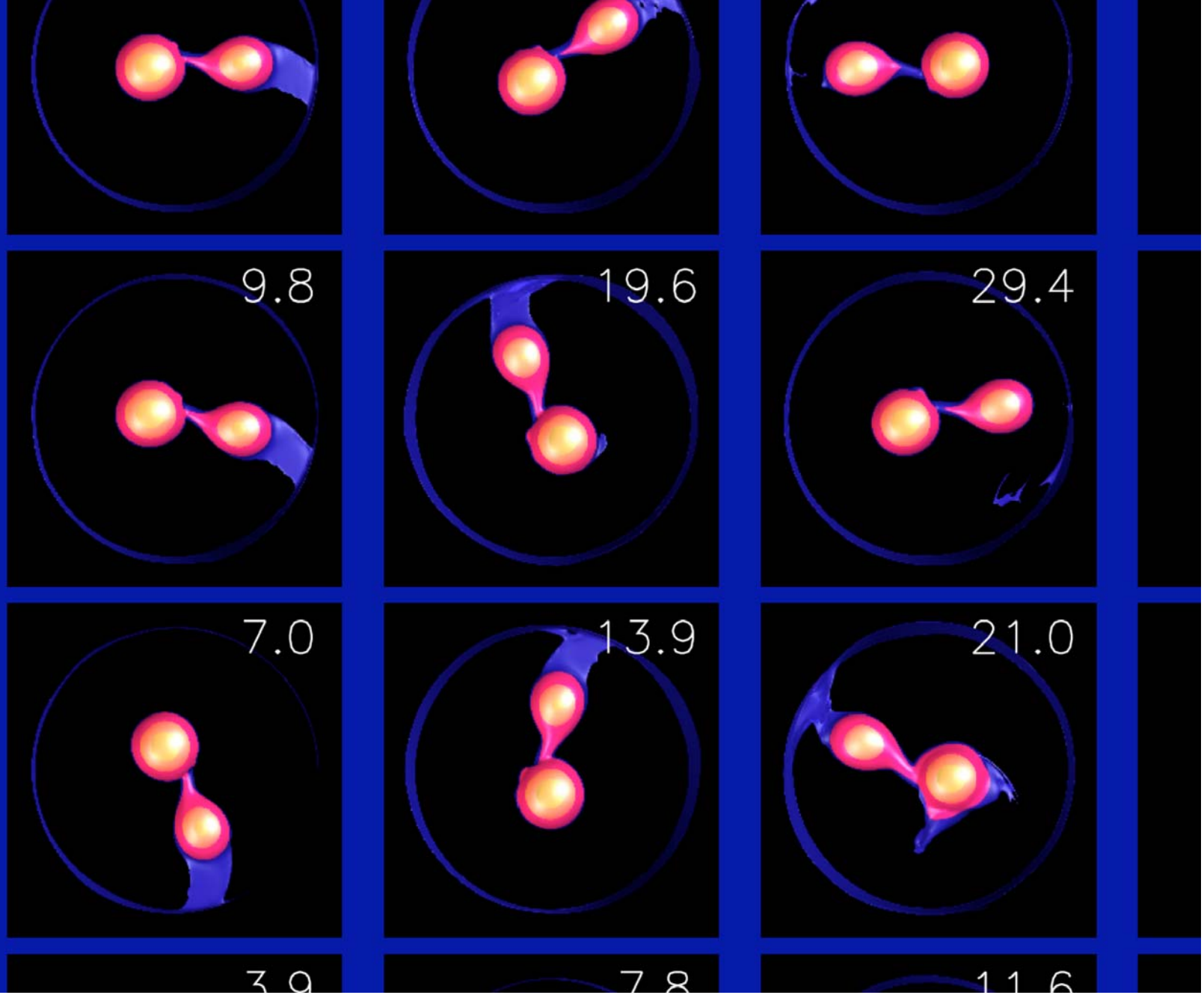
stars lifetime << 100 yr $^{-1}$

nrate of RCB stars from WD merger ~2 st

lifetime 10^4 – 10^5 yr

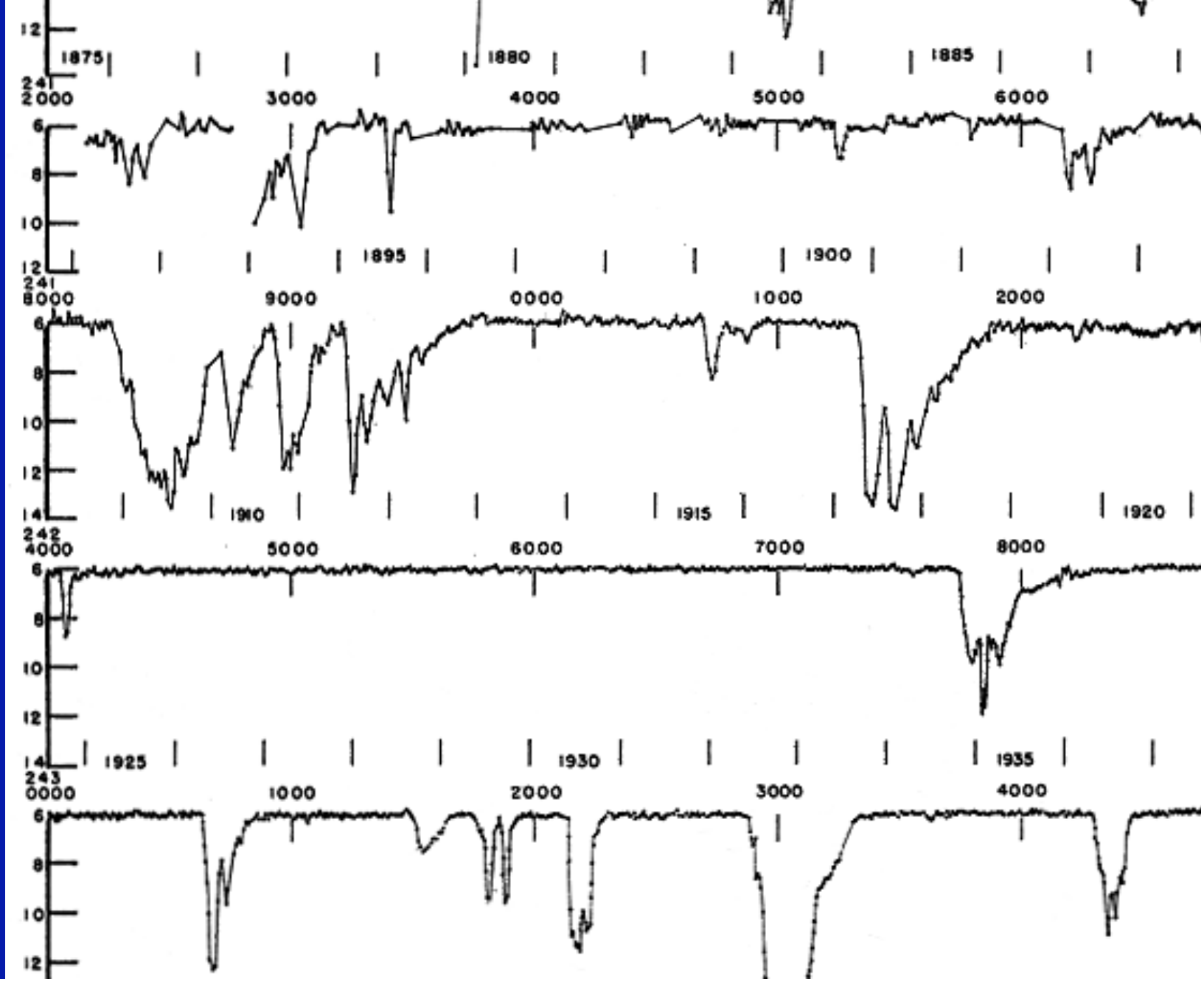
Final Helium Shell Flash vs White Dwarf

- Abundances (He/C, ^{13}C, ^{18}C
- Mass
- Lifetime


9.8
19.6
29.4
7.0
13.9
21.0

R Coronae Borealis

- Rare Examples of Stellar Evolution
- Laboratory for Study of Formation and Evoluti
- R CrB discovered to be variable in 1795
- About 35 RCB stars known
- F or G-Type Supergiants
- Hydrogen deficient; Carbon rich
- Pulsating variables
- Declines caused by carbon dust


12
1875
1880
1885
241
2000
3000
4000
5000
6000
6
8
10
12
1895
1900
241
8000
9000
0000
1000
2000
6
8
10
12
14
1910
1915
1920
242
4000
5000
6000
7000
8000
6
8
10
12
14
1925
1930
1935
243
0000
1000
2000
3000
4000
6
8
10
12

n of the Spectra of R Coronæ and R Scuti, and ra of R Aurigæ and R Andromedæ. By the spin, B.A.

The observations of this star show a curious rum. Throughout the observations the star n each night with different spectroscopes, and, feeble dispersion, the examination was con- ghest dispersion the star would bear was reached.

The spectroscope was very carefully in *a Coronæ*. I give the results of

1890, *March* 26.—Very clear; mag. Colour, yellowish white. N times irregularities, either dark or b

1890, *April* 10.—Continuous spe lines, one bright one strongly suspe believed more refrangible.

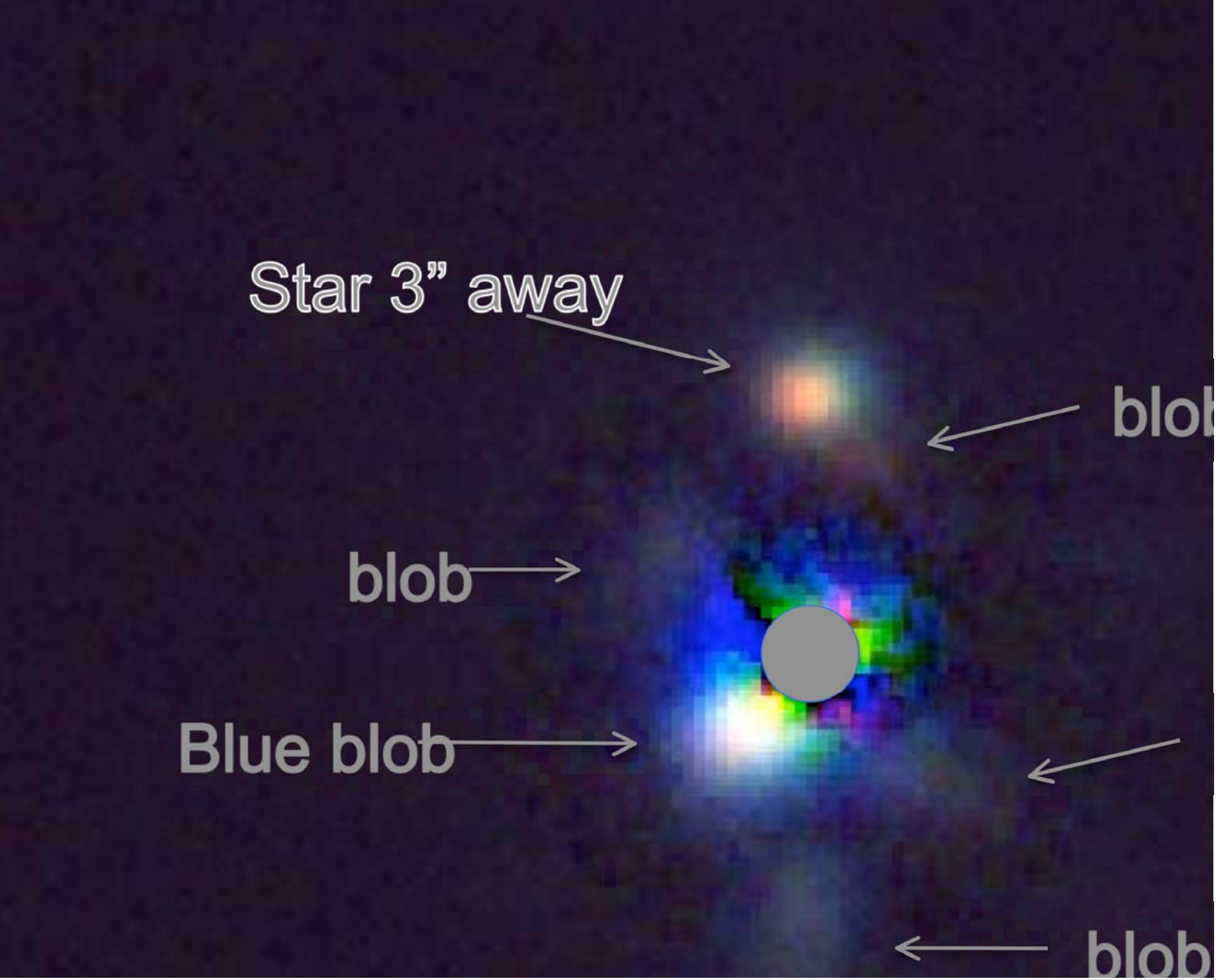
1890, *September* 8.—A most w place in this star's spectrum. Two appeared, one in the bluish-green, These bands are sharply defined o Bringing the spectrum to a line, b away in the violet—these may be b The star is now pale yellow. The r

1890, *September* 14.—The spe IV. type, since the bands fade aw side, but are sharply defined on the in the bluish-green was thought to fine lines; between the two bands The star is of the same magnitude a

1890, *October* 8.—Heavy mist, e telescopic work. The star is only have faded.

1890, *October* 10.—The star has continuous first type spectrum obse band in the bluish-green has disap violet is probably there still, but fain mentioned again suspected. The and the magnitude about the same.

R Scuti: 1890, *August* 21. *III.* Bands 1, 2, 3, of Dunér's nomencla


Star 3” away
blob
blob
Blue blob
blob