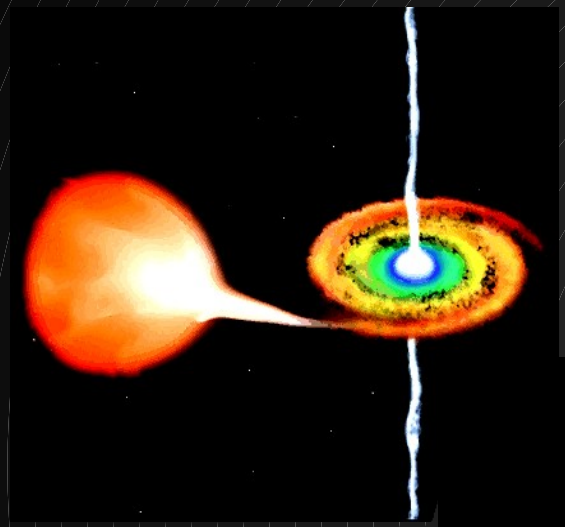
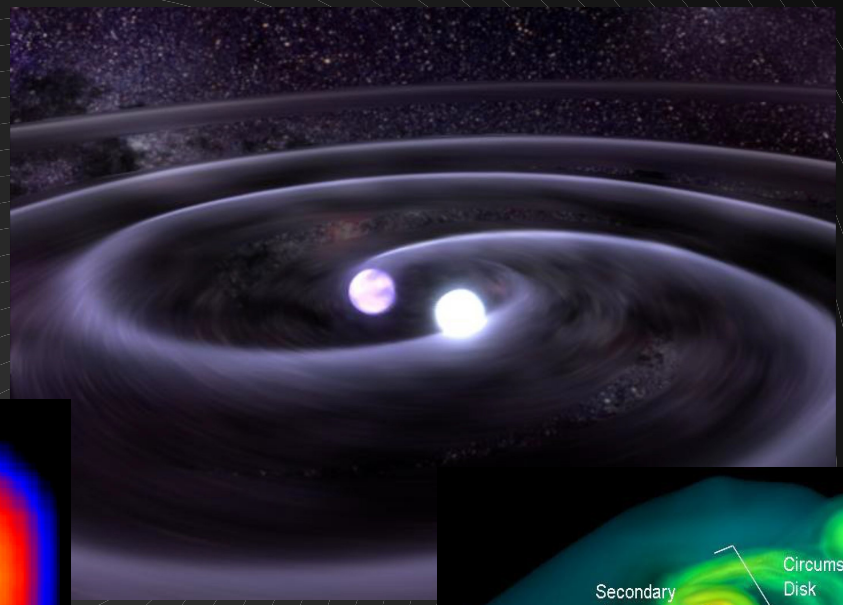
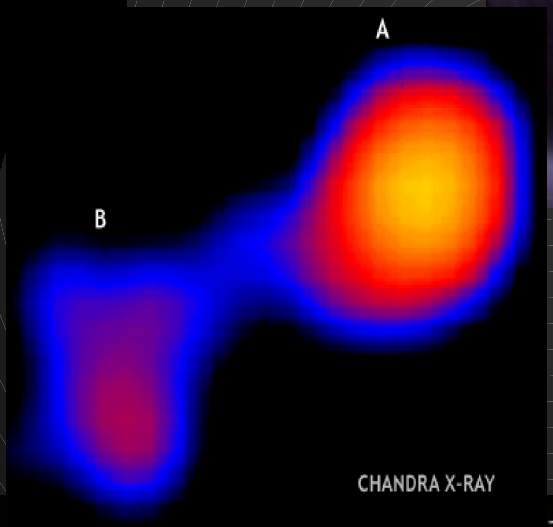
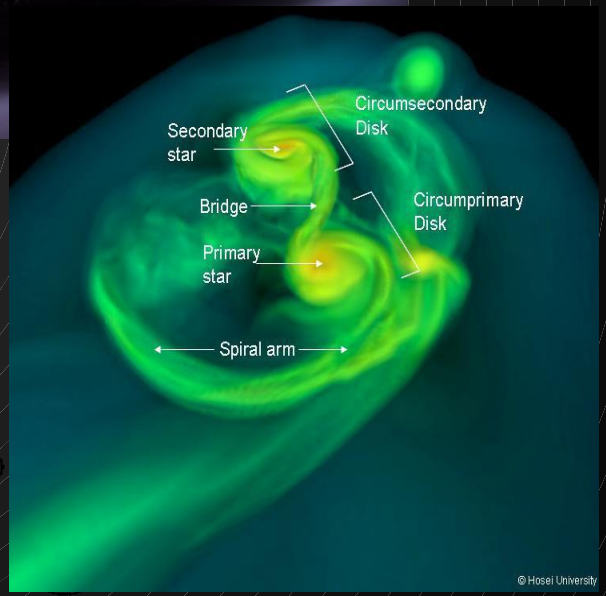
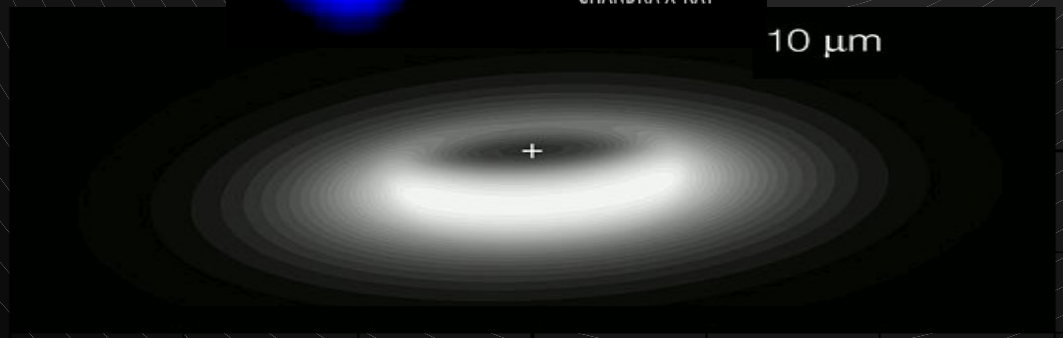
J-type carbon stars











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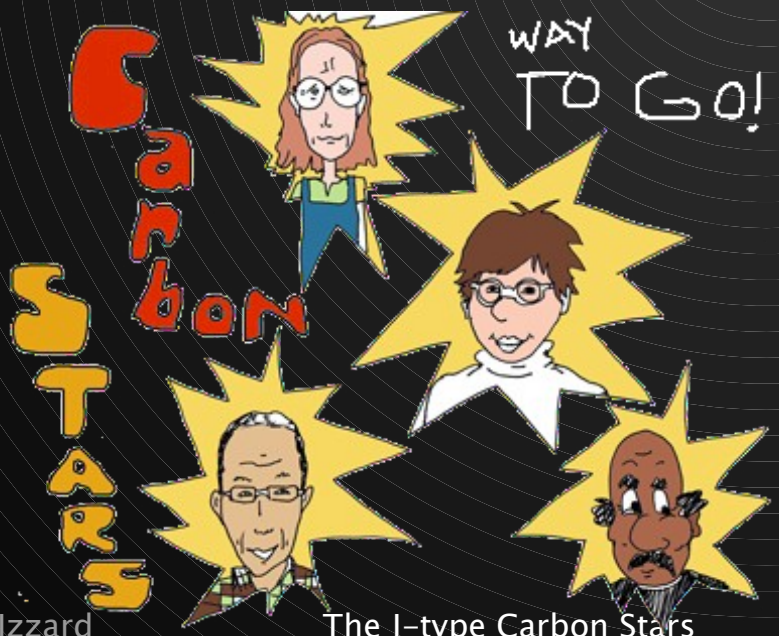
The Carbon Stars

- N stars : AGB third dredge up
- CH/CEMP stars : binaries, first ascent giants (N companion)
- R stars : mergers? (all single, no s-process)
- J stars : no idea at all!

$$C/O > 1$$

By number of particles!



The J-type Carbon Stars

N Stars

- AGB stars : third dredge up $\mathrm{M} \rightarrow \mathrm{S} \rightarrow \mathrm{C}$
- $T_{\mathrm{eff}} \sim 3000\,\mathrm{K}$ $L \gtrsim 10^4\,\mathrm{L}_\odot$ $M_{\mathrm{bol}} \sim -8.7\,\mathrm{to}\,-3$
  $M_V \sim -2.2$
  $\mathrm{C/O} \gtrsim 1 - 2$ *s*-process rich (Tc)
- Approx. solar metallicity (in MW)
- Qualitatively (semi-quantitatively) understood
- Lots of models!

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CH and CEMP stars

- (Halo) Binaries (at least CEMP-*s*)
- (Diluted) AGB composition
- Mass accretion from AGB companion (dead)
- Mostly giants $M_V \sim -1.8$ (dwarfs rare, dim)
- Halo stars, few in Galactic disc, fewer in bulge

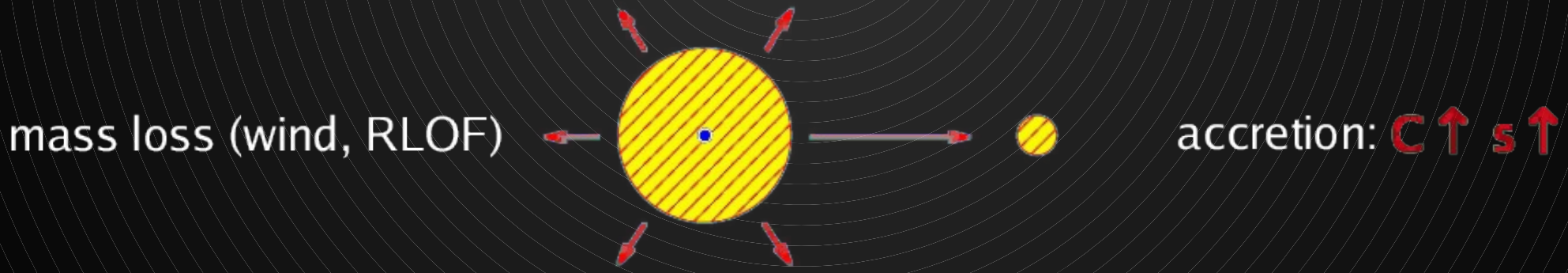


Image from Onno Pols

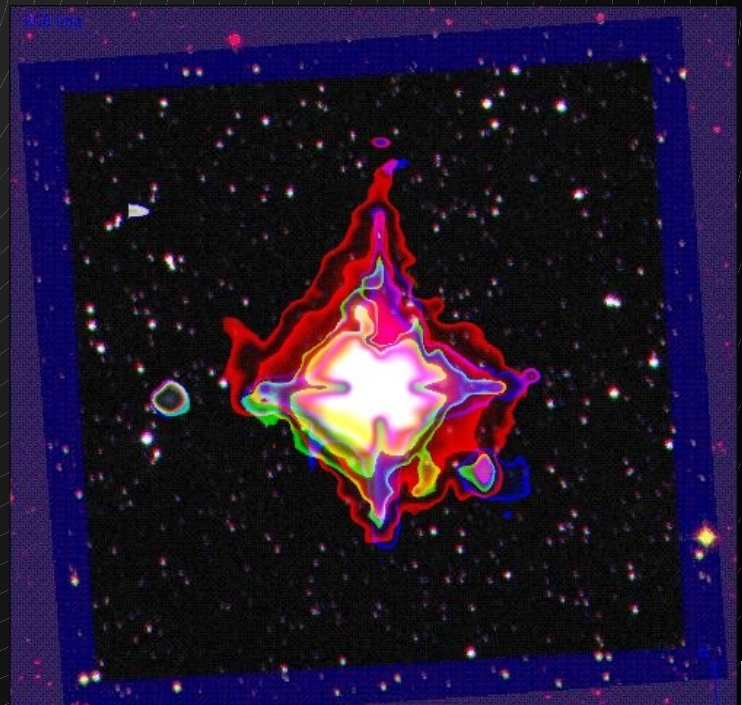
R stars

- All single stars : mergers? (popsyn consistent)
- C12, C13, N rich, Li?, no s-process
- Sub-solar thick disc population
- “Low”-L (helium-burning stars)
- I have an old talk on these...

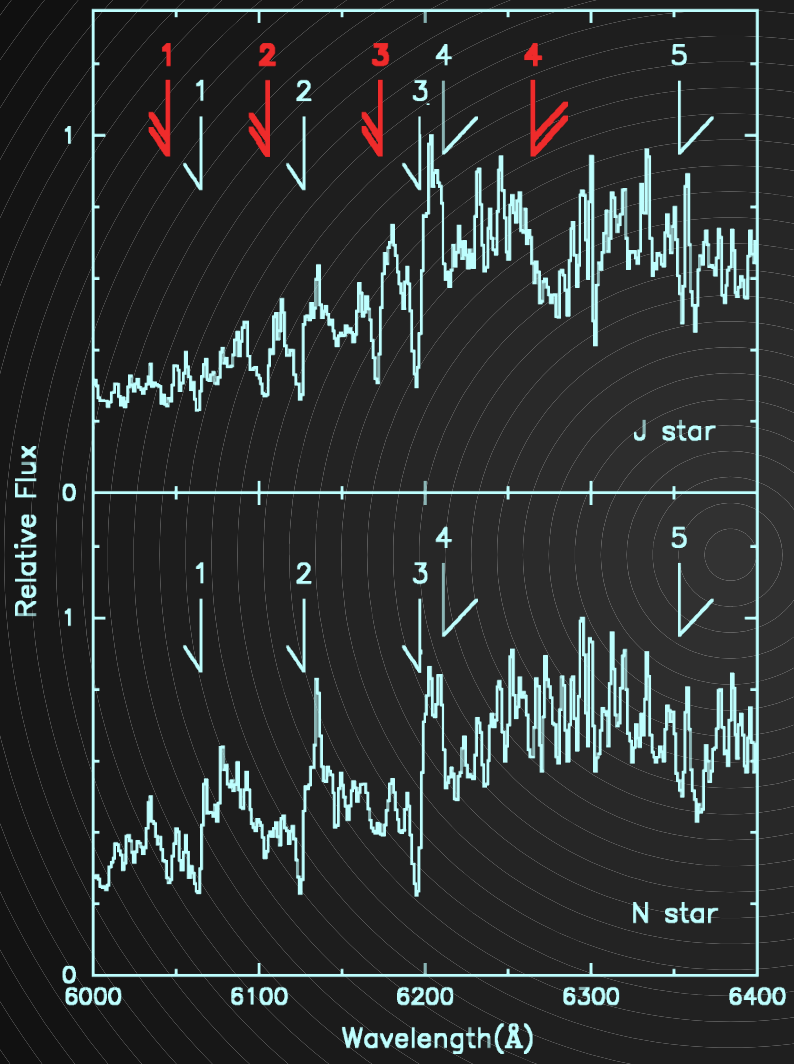
... for another time perhaps!

$M_V \sim 0$

$L \sim 100\,\mathrm{L}_\odot$



J Stars: C13-rich C-stars



Red = C13

A real mystery among the carbon stars

Morgan et al 2003 MNRAS 341, 534

Number statistics

- $N_{\rm J}/N_{\rm C} \sim 10-15\%$ in MW and LMC

  (Abia & Isern 2000, Morgan et al 2003: 1497 C stars in LMC: 156 J type)

- **J stars are not rare!**

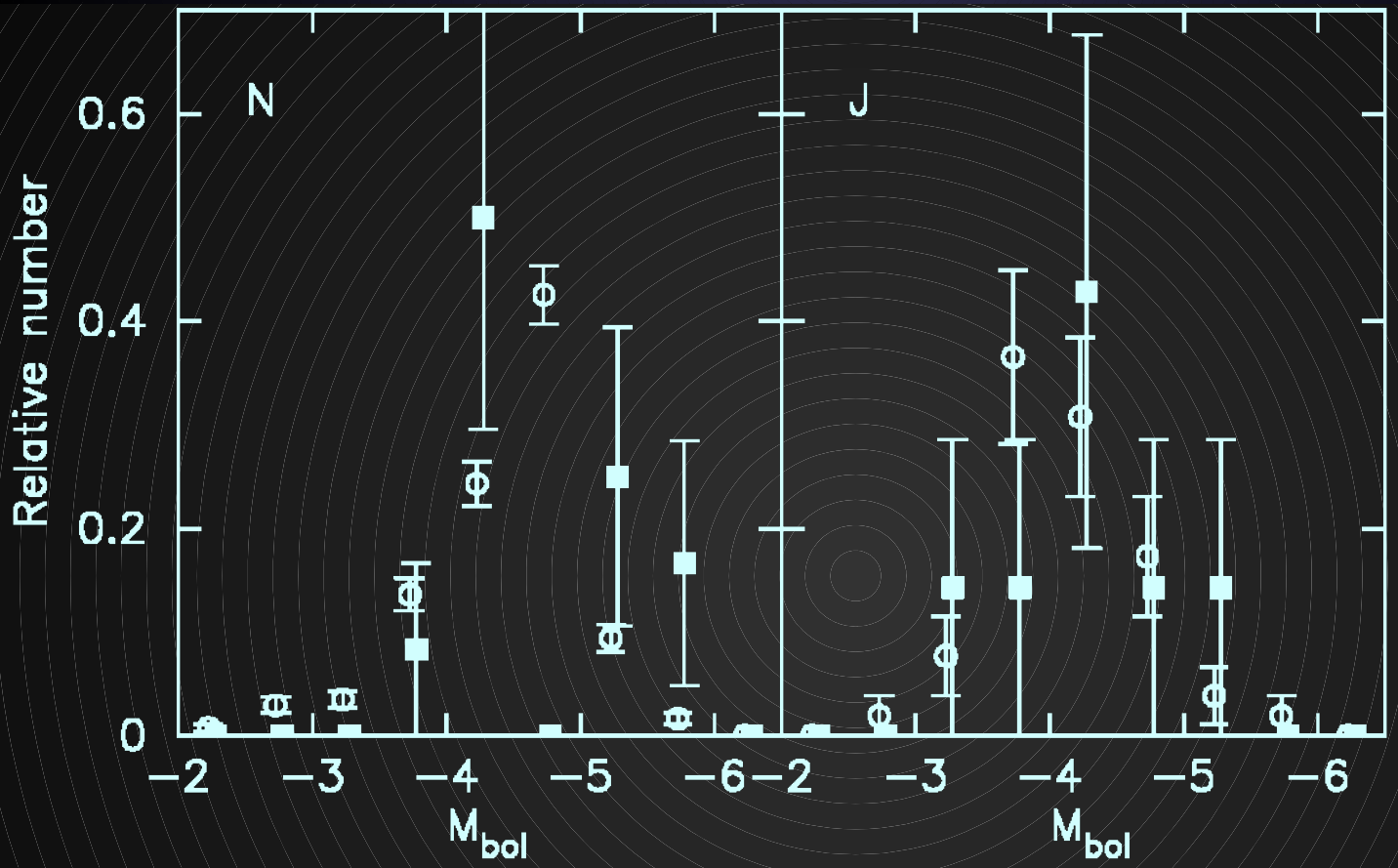
- Of which $\sim 15\%$ are "*bright J stars*" =

  AGB stars undergoing hot-bottom burning

  ($\sim 15\% \times 15\% \sim 2\%$ of all C stars i.e. *rare*)

- *Not* Mira pulsators (J=irregular/semi regular)

Luminosity Function



LMC stars

Figure 7. Relative frequency of carbon stars in M_{bol} intervals of 0.5 mag. The left-hand panel is for N stars and the right-hand panel is for J stars. The open circles are for normal carbon stars and the solid squares are for the Li-rich stars in Table 1(a).

Hatzidimitriou et al 2003 MNRAS 341,1290

Colour-magnitude

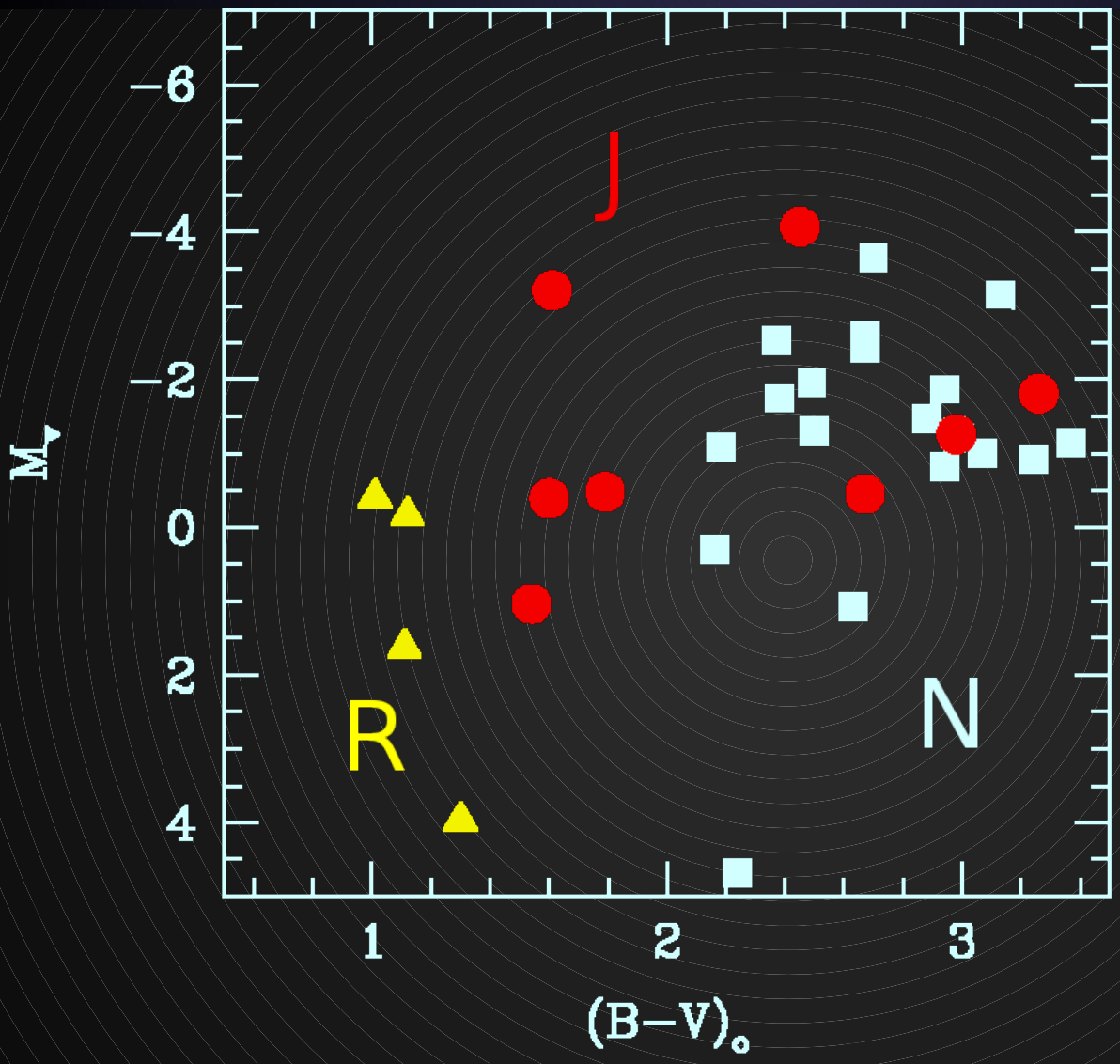


FIG. 6.—Observational H-R diagram for carbon stars. *Circles:* J-type stars in this study, *squares:* N-type stars; *triangles:* R-type stars. Data for N and R stars are taken from Alksnis et al. (1998).

Galactic stars

Abia and Isern 2000
A&A 536, 438

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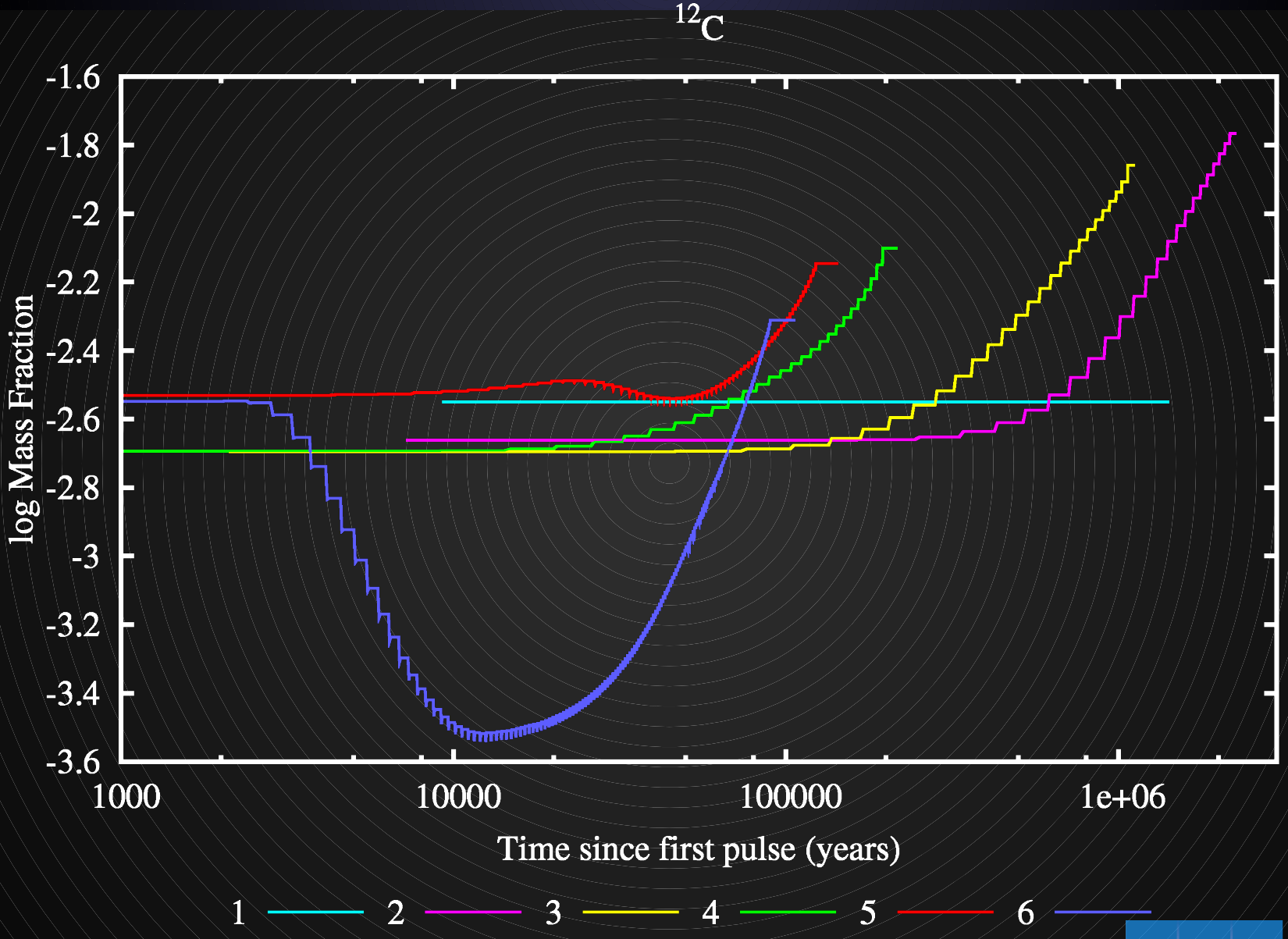
Bright J Stars = AGB Stars



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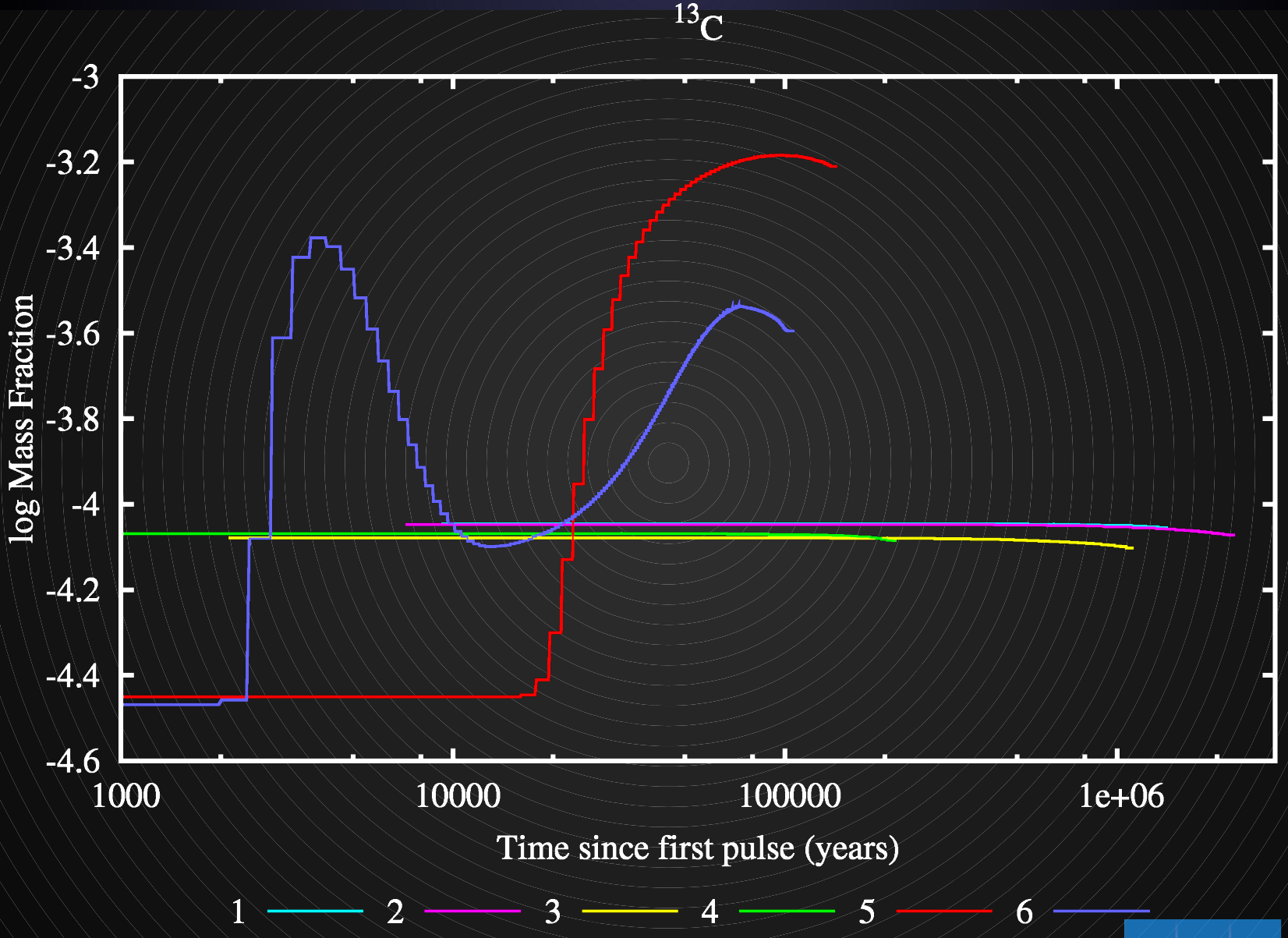
Bright J Stars = AGB Stars



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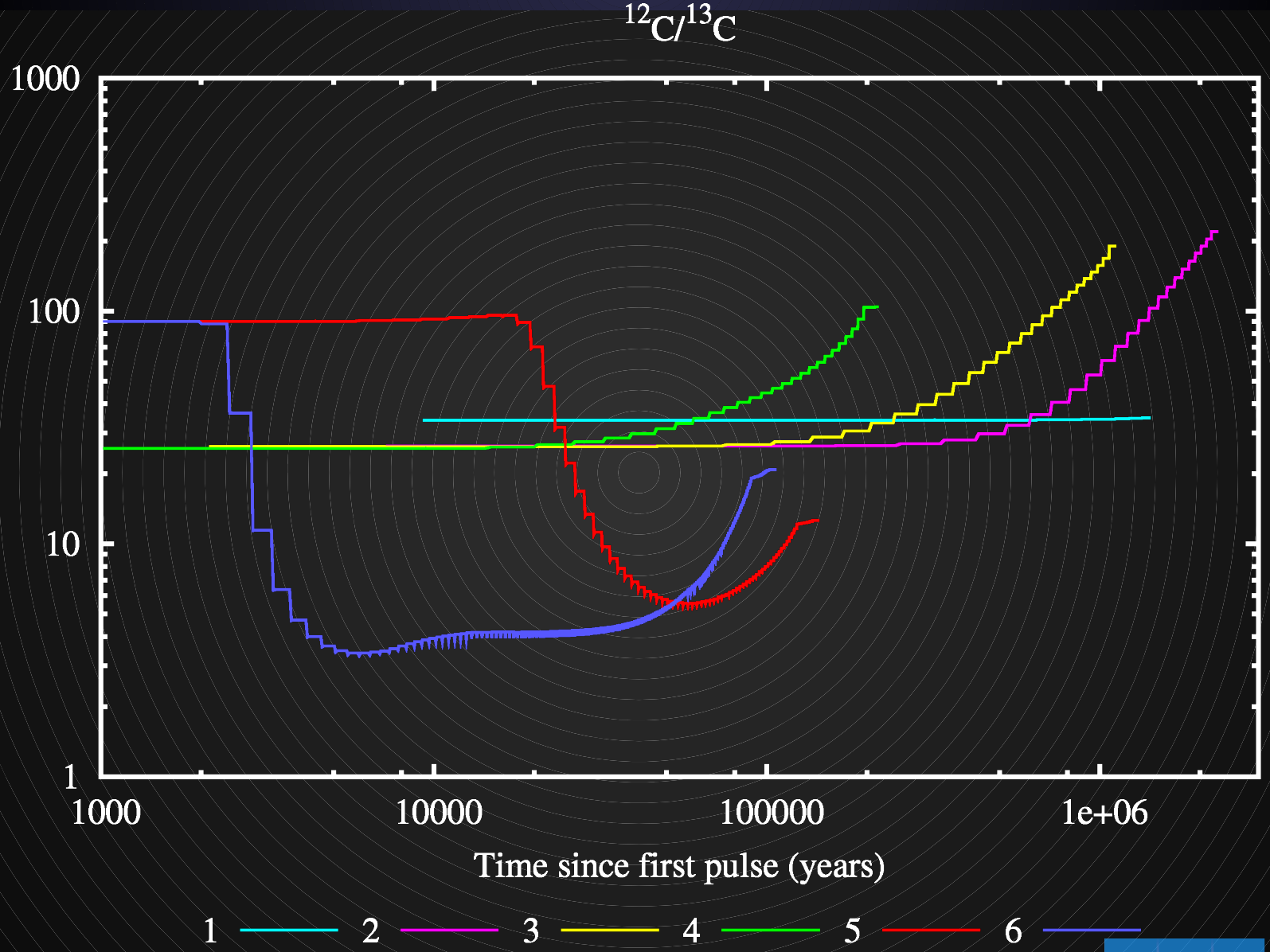
Bright J Stars = AGB Stars



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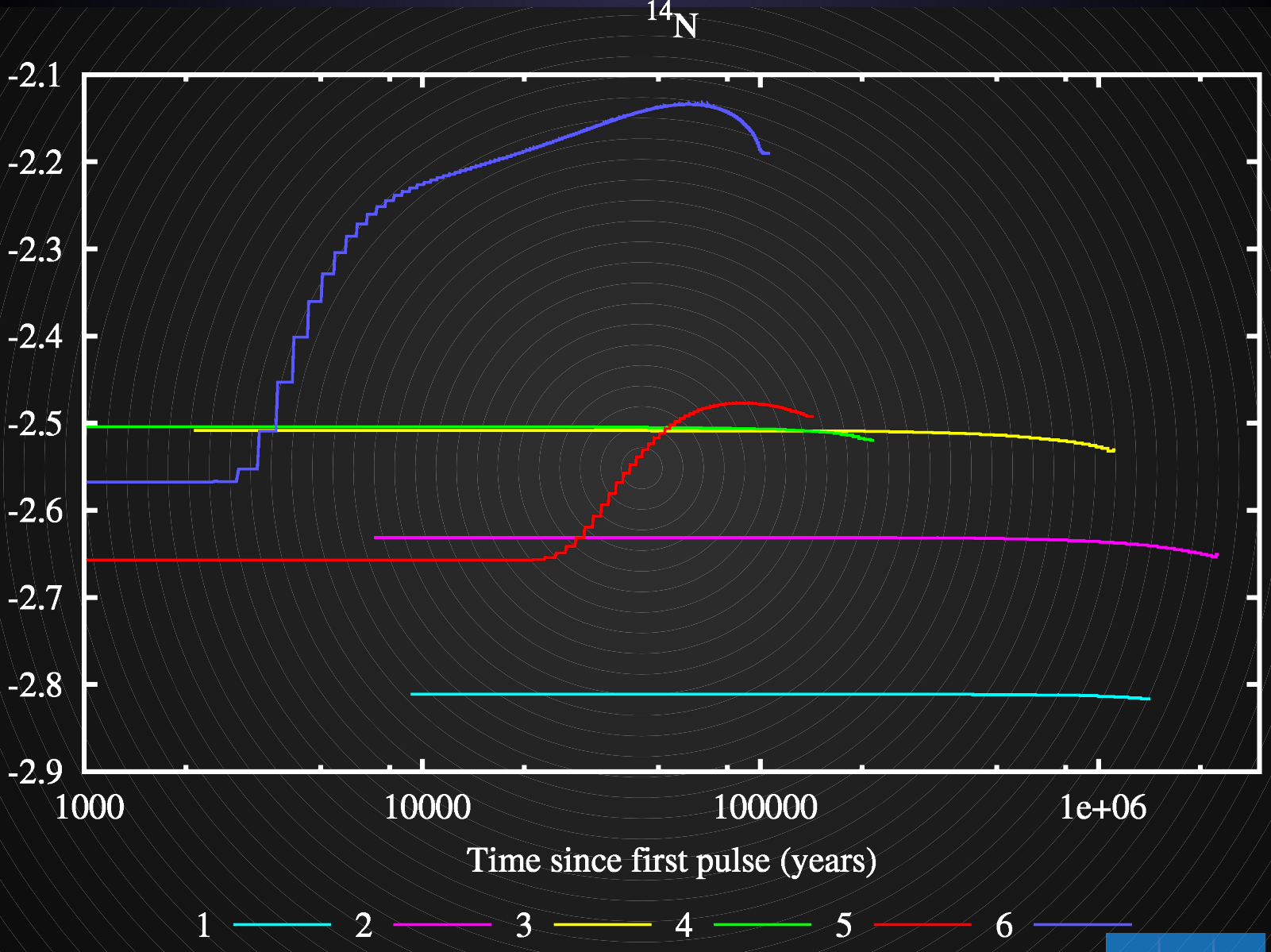
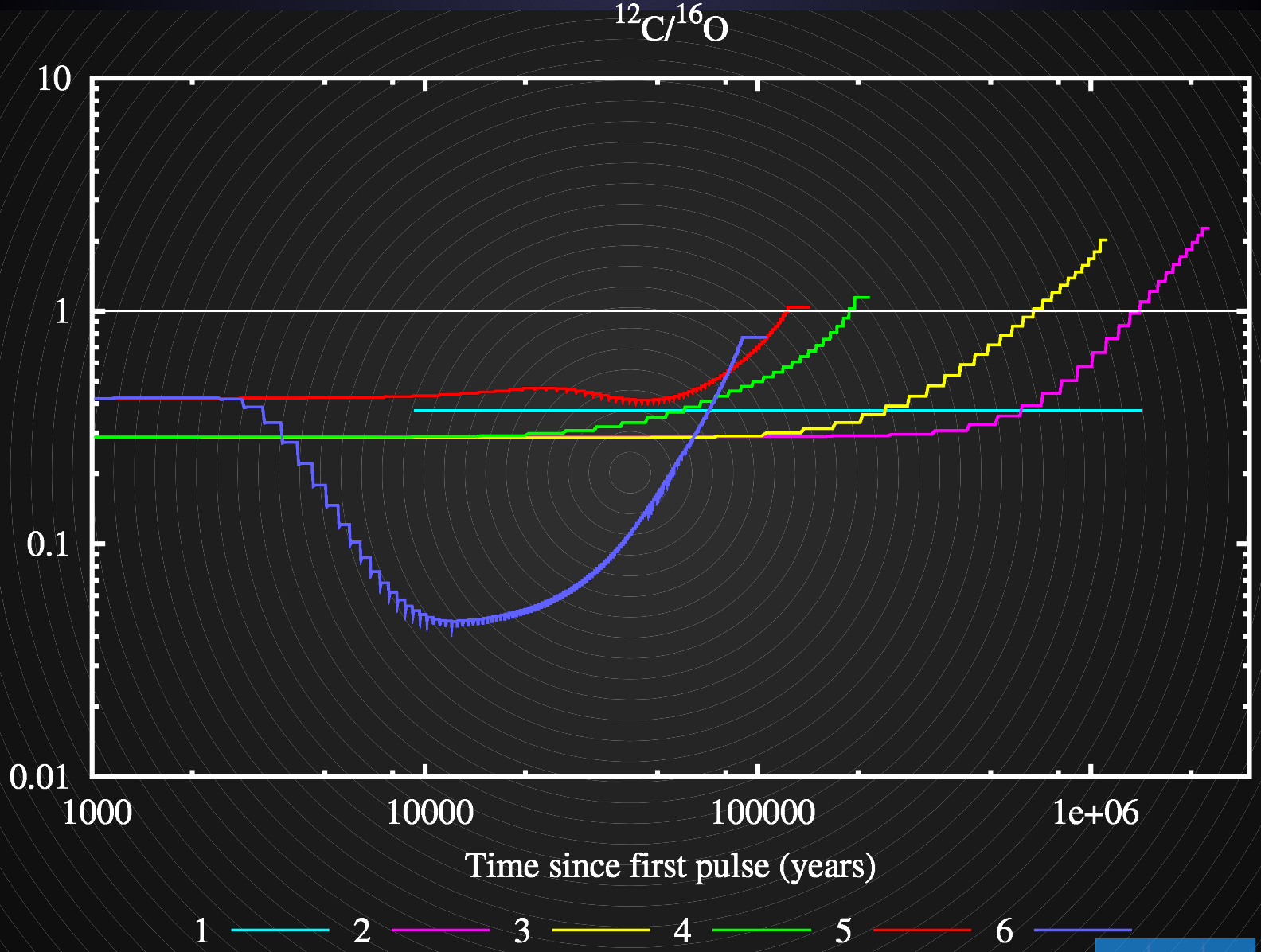
Bright J Stars = AGB Stars

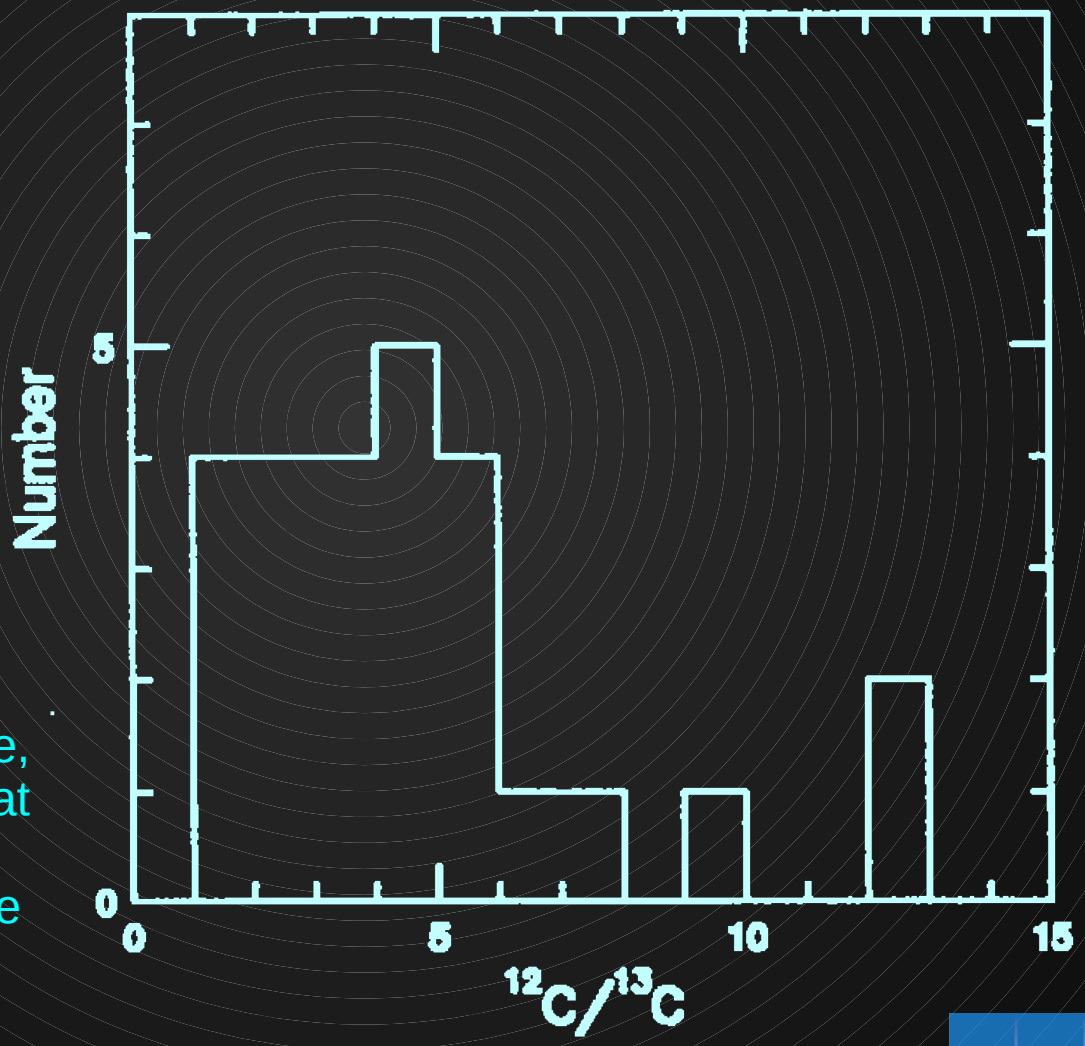


Bright J Stars = AGB Stars



C13 ratios observed

- Ohnaka+Tsuji 1999 A&A 345,233



See also
Harris et al 1987
ApJ 316,294 :
"No form of the CNO cycle, in any astrophysical site, at any temperature, can explain the ratios in J-type carbon stars"

Lithium vs $^{12}C/^{13}C$

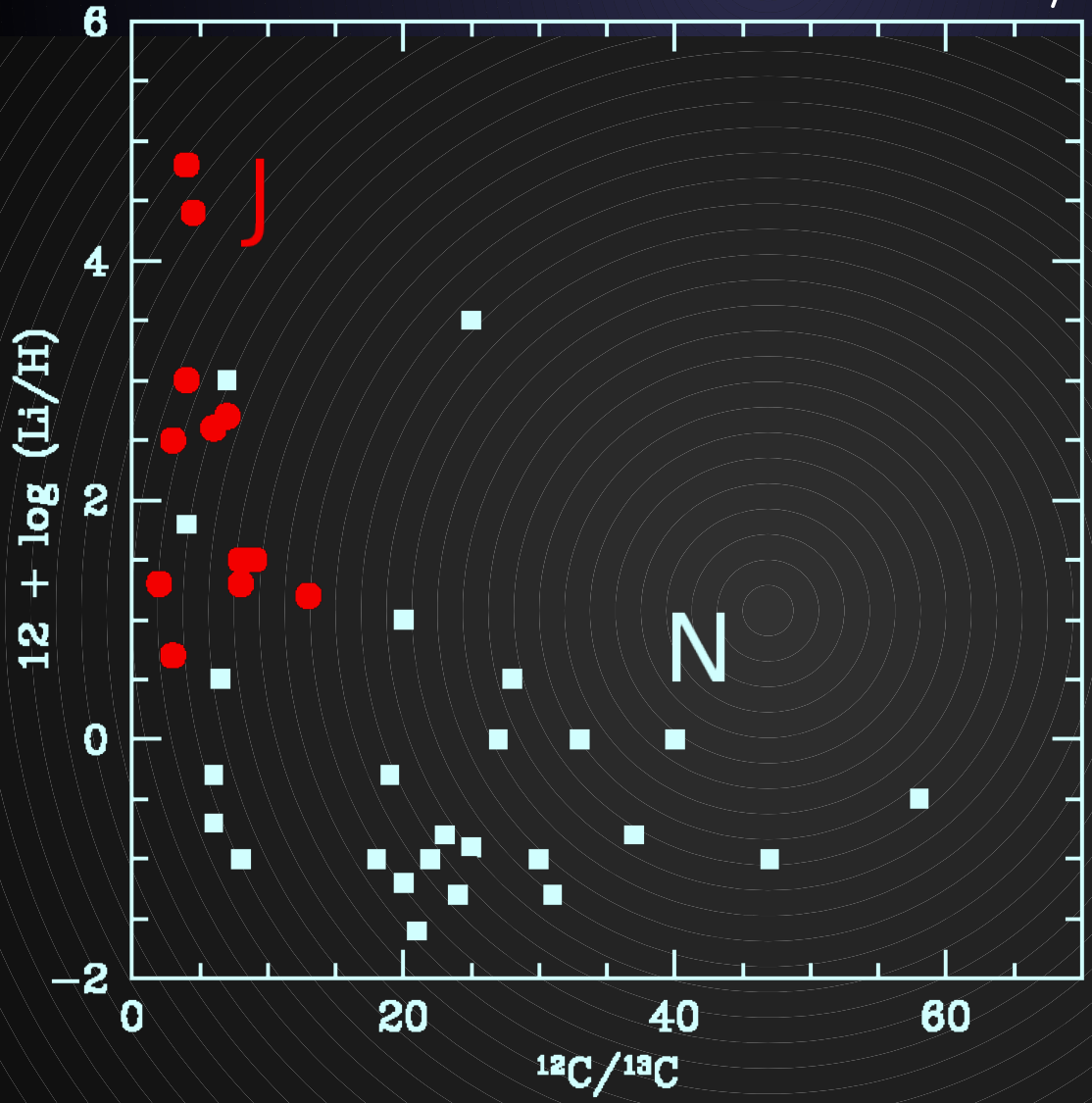


FIG. 2.—Li abundances vs. $^{12}C/^{13}C$ ratios in J stars in this work (*circles*) and N stars (*squares*) from Abia & Isern (1997). All the J stars are Li-rich. Note that there are some Li-rich N stars with low carbon isotope ratios.

Galactic stars

Abia and Isern 2000
A&A 536, 438

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Chemistry compared

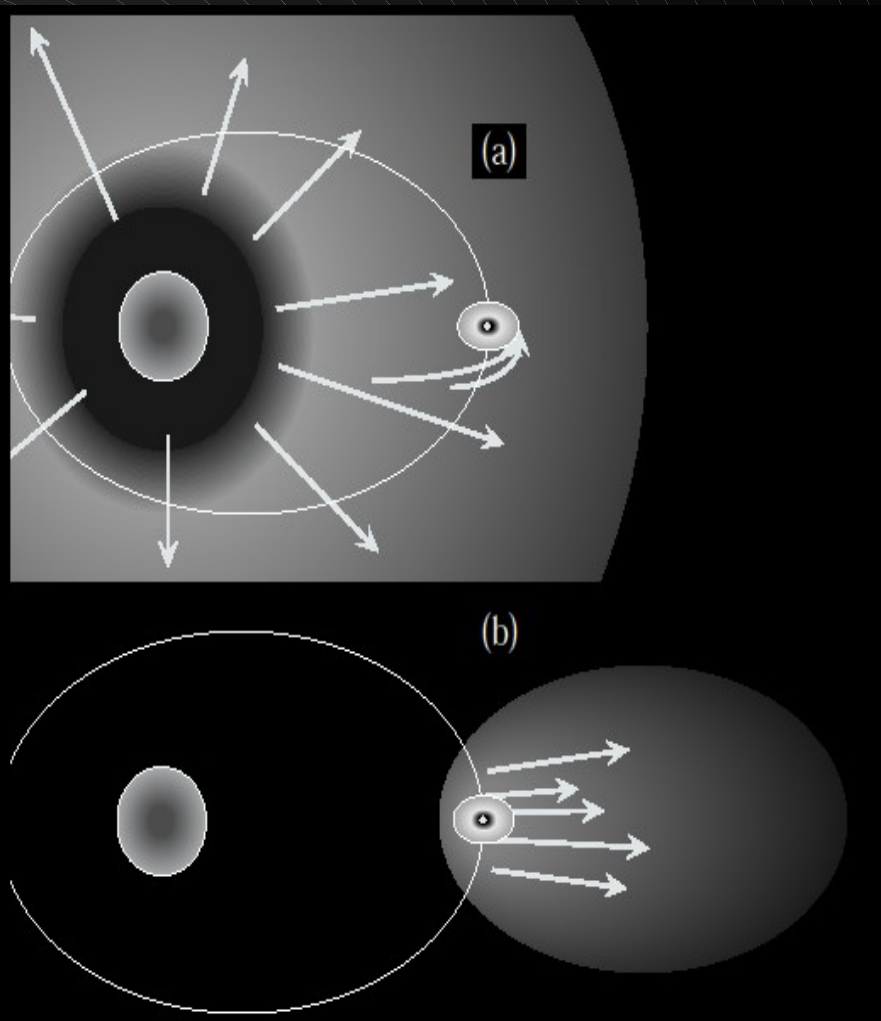
Star	$\frac{C}{O}$	$\frac{^{12}C}{^{13}C}$	$\frac{C}{N}$	$\frac{^{16}O}{^{17}O}$	$\frac{^{16}O}{^{18}O}$	[s/Fe]	Tc?	Li?
N	>1.1	20-100	>1	500-4000	700-2400	+1 to +2	yes	no
J	>1.1	1-10	5	350-850	150-1600	0	no	Yes (75%)
Sun	0.3	89	4.8	2660	490	0	no	no
$2\,M_\odot$ **After 1DUP**	0.3	7-25	~ 1	300-650	600	0	no	no

Compiled by John Lattanzio

Silicate Discs

- 10% of J stars show *silicate discs* SiO_2
- But … Silicate = oxygen rich!
- Binary model, disc is around
  - The other star or
  - Both stars (Deroo etal 2007 A&A467,1093)
- 1 yr disc replenishment but

  14 yr obs. (Yamamura et al 2000 A&A 363,629)
- *All silicate C-stars are J stars*
- Not all J stars have silicates: non-eq chemistry!



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The J Star Mystery!

- Not yet sure how to put all the clues together
- Some are HBBing AGB stars, some have discs
- The others (which are the majority)?
- Ideas?
  - Binary origin? (no binary statistics)
  - Novae? (A+B grains? Low-mass CO nova?)
  - C-rich supernoave? (no idea about this!)
  - He-flash mixing? (c.f. R stars); Non-eq dust chemistry?
  - AGB models wrong? (always the case! HBB difficult)
  - Extra mixing (but makes N and C/O<1)
- Fame and fortune if you can solve it!

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