AN OVERVIEW OF ULTRACOMPACT LOW-MASS X-RAY BINARIES

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ULTRACOMPACT LMXBs

- $P_{orb} \lesssim 80$ min
- Very low-mass ($\lesssim 0.1\,M_\odot$) hydrogen-poor donor
- Accreting neutron star primary (or black hole?)
- Binary separation $\sim 10^{10}$ cm (1 light-s) (Earth-Moon distance)
- Mass transfer driven by gravitational radiation
- Optical emission dominated by X-ray heated accretion disk, UV-bright. No hydrogen lines.

HOW ARE ULTRACOMPACT LMXBs IDENTIFIED ?

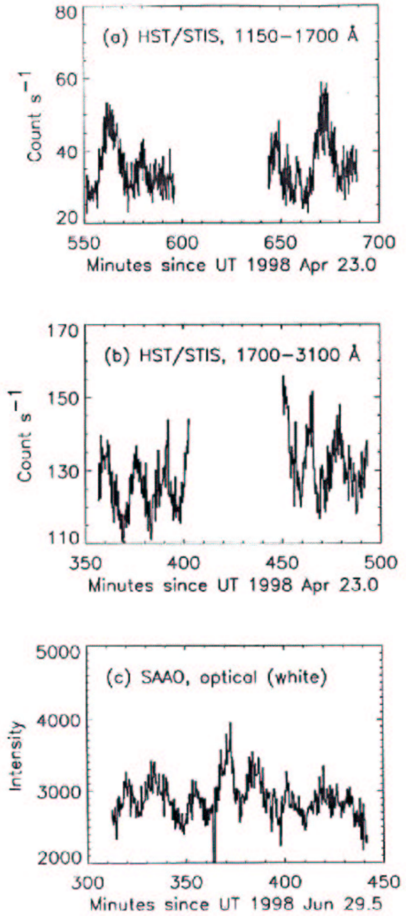
DIRECT

- Period in X-ray intensity (dips)
- Period in optical/UV intensity (BUT mHz QPOs!)
- Doppler shifts of X-ray pulsations (fast)
- Optical reprocessing ~~of~~ sideband of X-ray pulsations

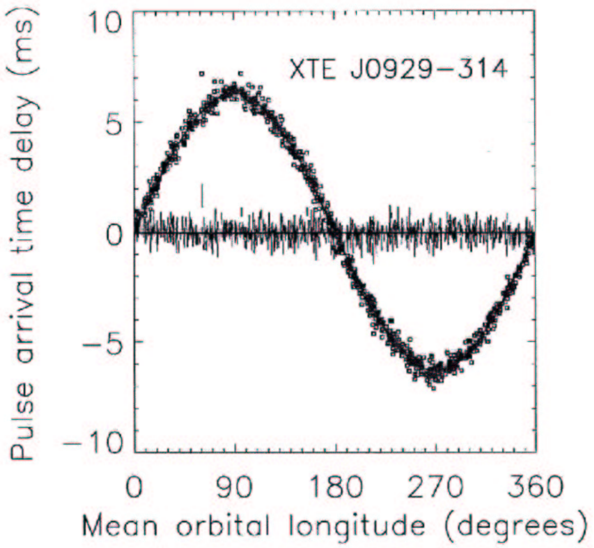
INDIRECT

- L_x-L_{opt} correlation (van Paradijs + McClintock 1994)
- Composition from spectroscopy
- Outer edge radius of accretion disk from opt. spectroscopy

NON-ORBITAL VARIABILITY IN 4U 1626-67



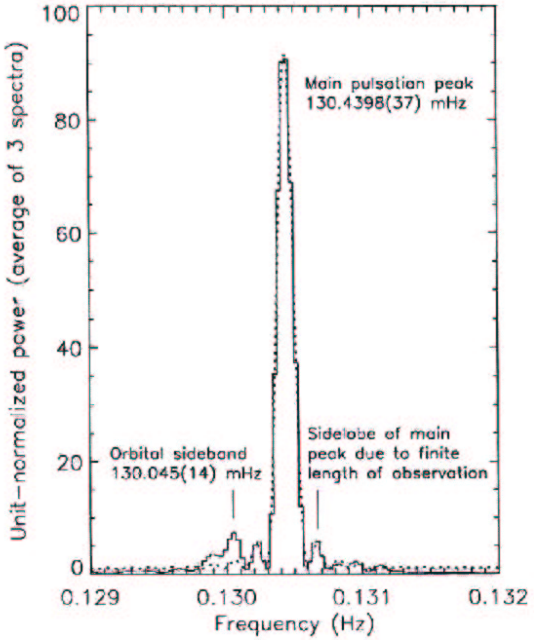
Chakrabarty et al. 2001



Galloway et al. 2002

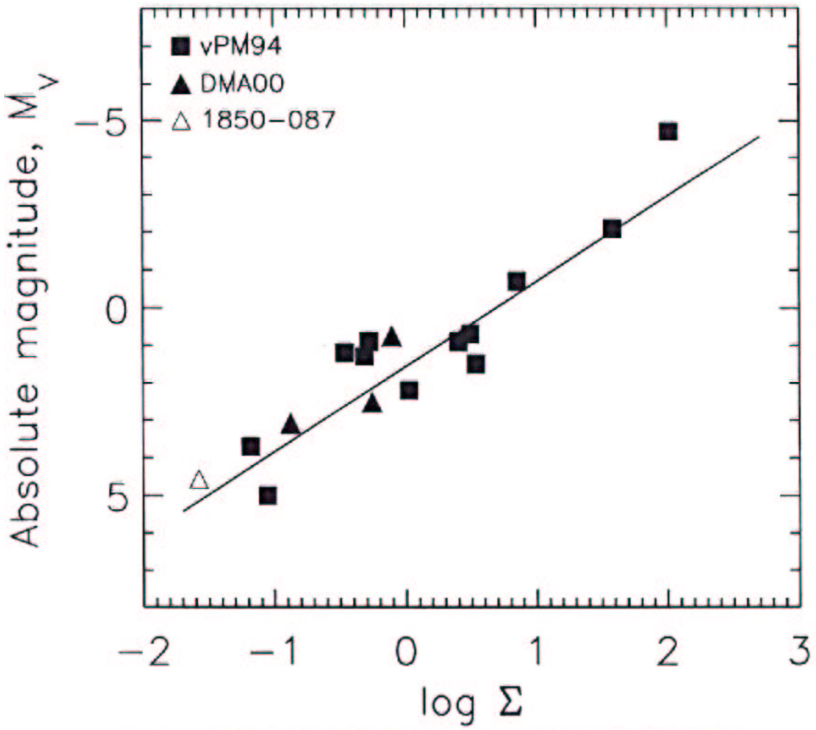
OPTICAL ORBITAL SIDEBAND IN 4U 1626-67

(Discovered by Middleditch et al. 1981)

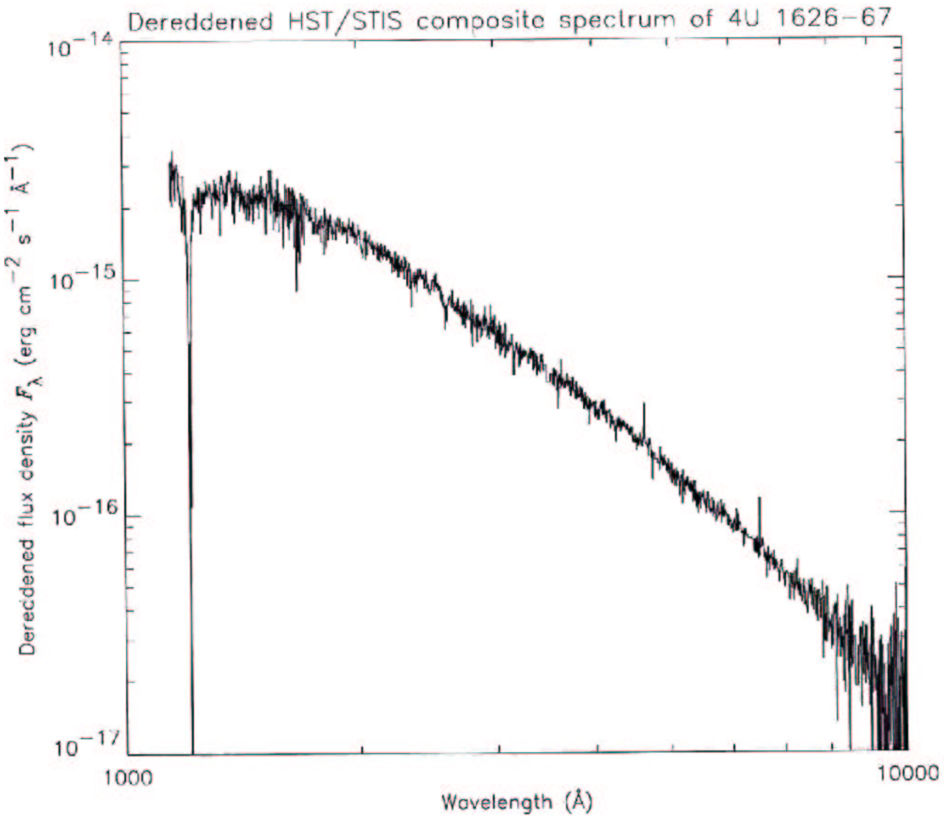


Chakrabarty (1998)

see van Paradijs + McClintock 1994
A+A, 290, 133



$$\boxed{\Sigma = \left(\frac{L_x}{L_{Edd}}\right)^{1/2}\left(\frac{P_{orb}}{1\,hr}\right)^{2/3}}$$



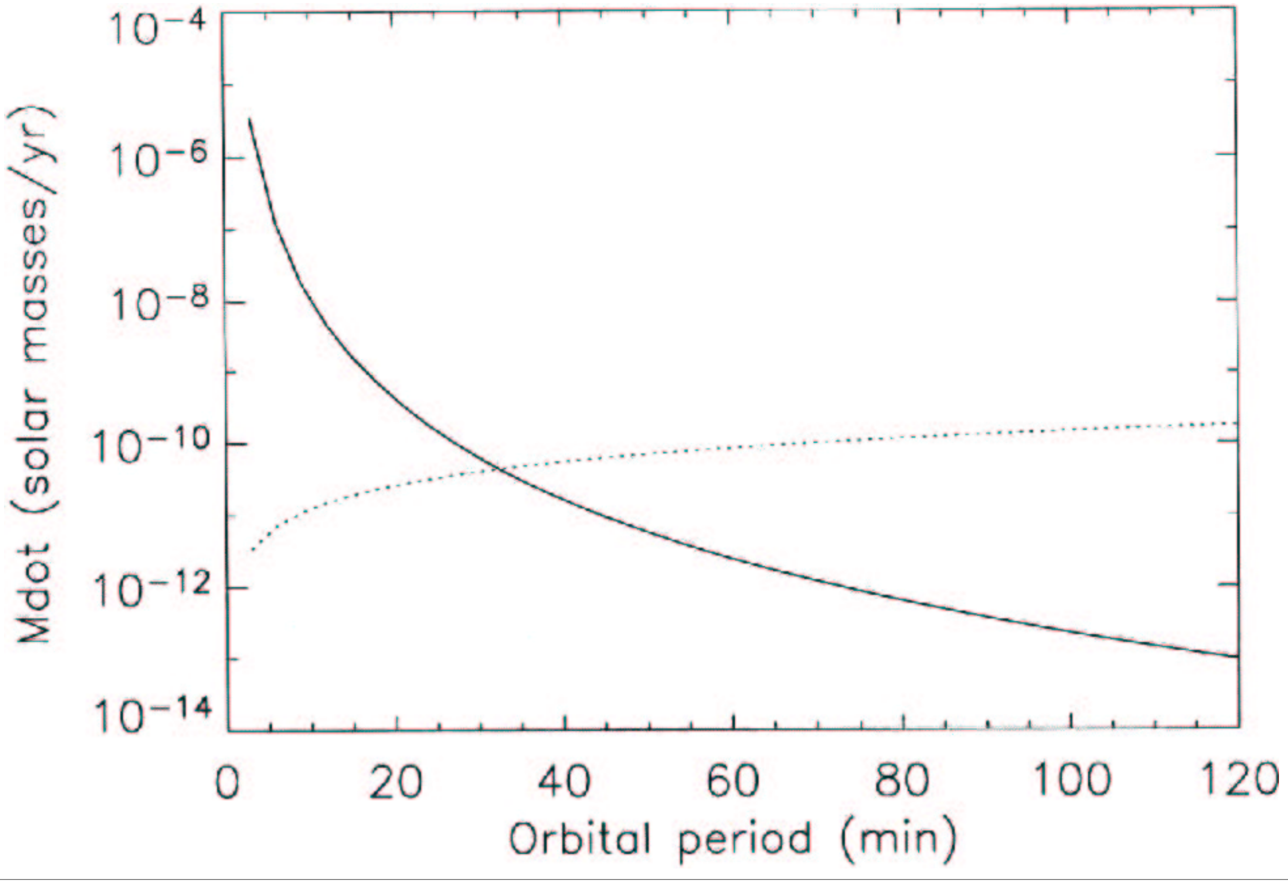
Wang + Chakrabarty
2002

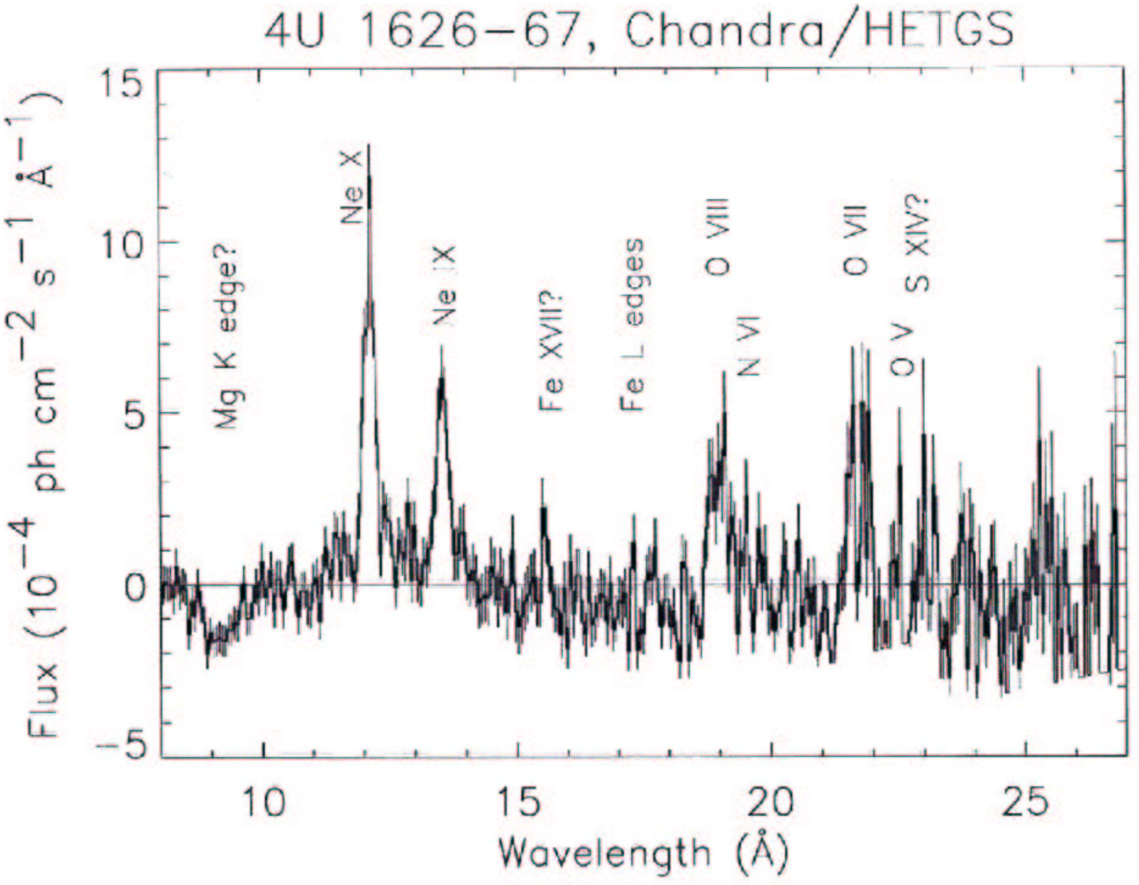
ULTRACOMPACT LMXBs

Galactic latitude

Name	Location	Porb	b	Remarks
4U 1820-30	NGC 6624	11 min	−8°	X-ray burster
4U 1850-087	NGC 6712	21 min (?)	−4°	X-ray burster
4U 1626-67	field	42 min	−13°	7.6 s pulsar
XTE J1751-305	field	42 min	0°	2.3 ms pulsar
XTE J0929-314	field	43.6 min	+14°	5.4 ms pulsar
4U 1916-05	field	50 min	−8°	X-ray burster (3.7 ms spin)
CANDIDATES				
4U 0614+09	field		−3°	
2S 0918-549	field		−4°	
4U 1543-624	field		−6°	
4U 1822-00	field		+6°	
X1832-330	NGC 6652		−11°	

Issues:
- GC/field
- Latitude
- Porb
- NS magnetic field, msec PSRs (1808?)
- transient or persistent





Schulz et al. 2001

PHOTOELECTRIC ABSORPTION IN 4U 1626-67

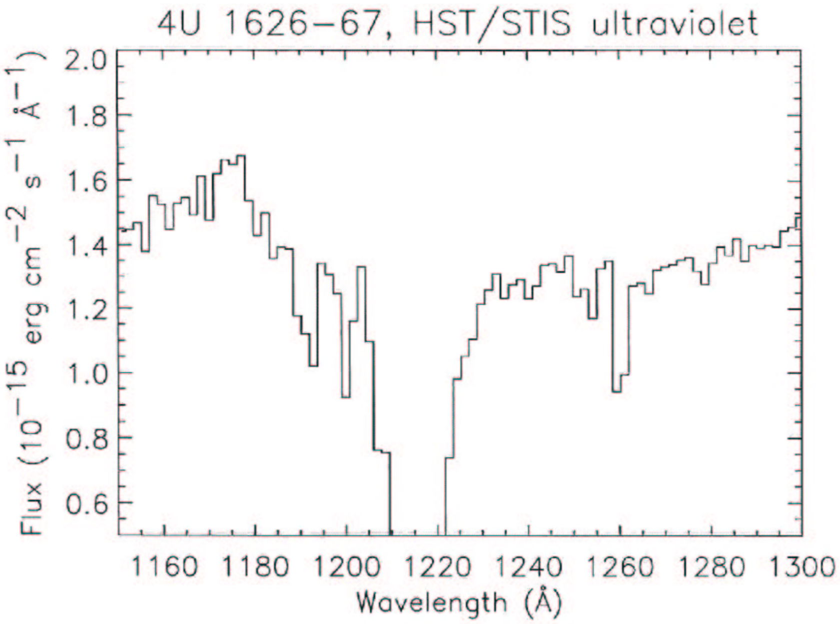
Edge	Total N_Z (10^{17} cm^{-2})	Implied N_H (10^{21} cm^{-2})	Inferred Local N_Z (10^{17} cm^{-2})
Ne (K)	5.2 ± 2.5	3.7 ± 1.8	4.4 ± 2.5
Fe (L)	0.35 ± 0.16	1.1 ± 0.5	0.15 ± 0.15
O (K)	25 ± 12	3.3 ± 1.6	20 ± 12

Schulz et al. 2001

$$\boxed{\text{From H } (L_y\alpha):\quad N_H = (0.62 \pm 0.07) \times 10^{21}\ \text{cm}^{-2}}$$

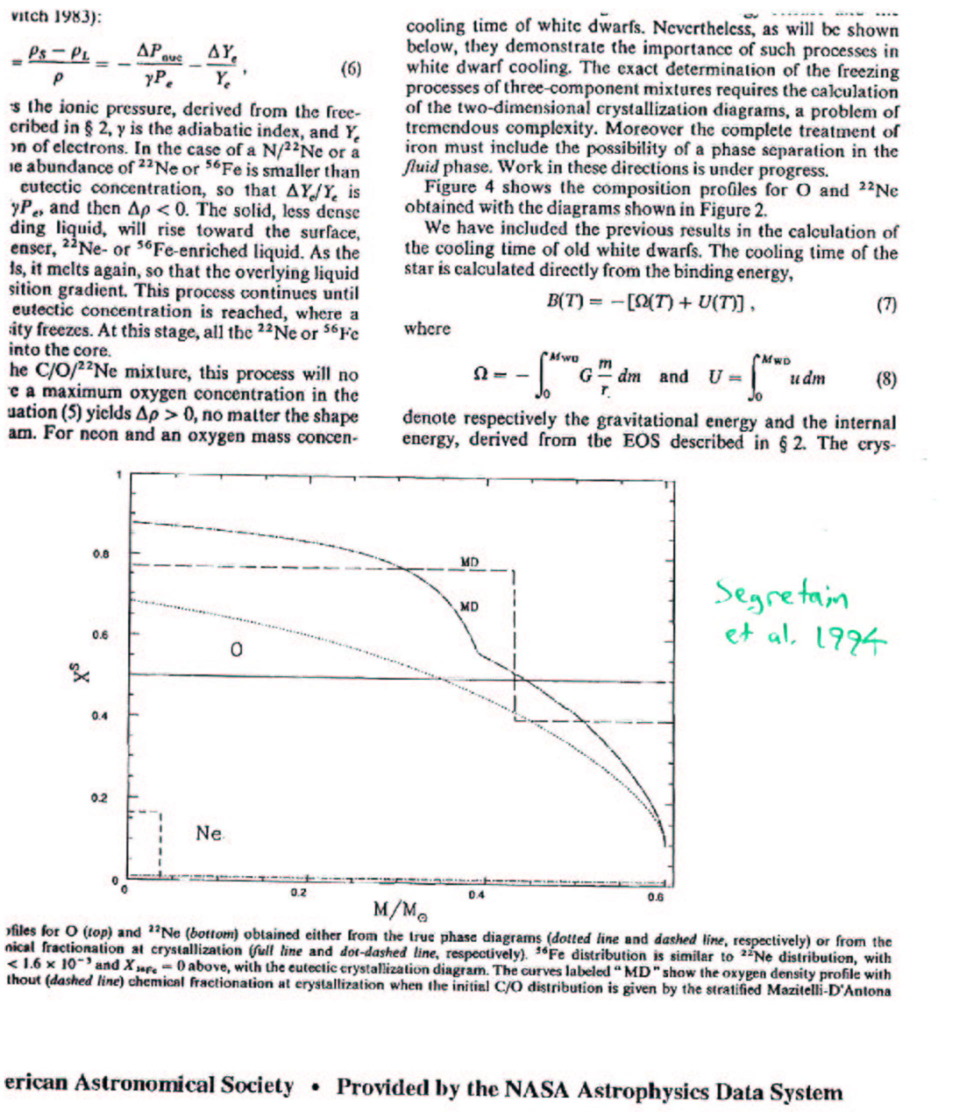
- Ne, O edges stronger than expected
- Emission lines from same elements ⇒ local absorption
- Local $N(Ne)/N(O) = 0.22 \pm 0.15$

Expect $< 10^{-2}$ for He-WD
$\sim 10^{-2}$ for ordinary C-O WD (Ne^{22})
15-20% for inner core of crystallized C-O WD



Wang + Chakrabarty 2002

$N_H = (0.62 \pm 0.07) \times 10^{21}$ cm^{-2}



vitch 1983):

$$= \frac{\rho_S - \rho_L}{\rho} = -\frac{\Delta P_{\rm auc}}{\gamma P_e} - \frac{\Delta Y_e}{Y_e}, \qquad (6)$$

·s the ionic pressure, derived from the free-
cribed in § 2, γ is the adiabatic index, and Y_e
›n of electrons. In the case of a N/^{22}Ne or a
ıe abundance of ^{22}Ne or ^{56}Fe is smaller than
eutectic concentration, so that $\Delta Y_e/Y_e$ is
γP_e, and then $\Delta\rho < 0$. The solid, less dense
ding liquid, will rise toward the surface,
enser, ^{22}Ne- or ^{56}Fe-enriched liquid. As the
ls, it melts again, so that the overlying liquid
sition gradient. This process continues until
eutectic concentration is reached, where a
ity freezes. At this stage, all the ^{22}Ne or ^{56}Fe
into the core.

he C/O/^{22}Ne mixture, this process will no
·e a maximum oxygen concentration in the
uation (5) yields $\Delta\rho > 0$, no matter the shape
am. For neon and an oxygen mass concen-

cooling time of white dwarfs. Nevertheless, as will be shown below, they demonstrate the importance of such processes in white dwarf cooling. The exact determination of the freezing processes of three-component mixtures requires the calculation of the two-dimensional crystallization diagrams, a problem of tremendous complexity. Moreover the complete treatment of iron must include the possibility of a phase separation in the *fluid* phase. Work in these directions is under progress.

Figure 4 shows the composition profiles for O and ^{22}Ne obtained with the diagrams shown in Figure 2.

We have included the previous results in the calculation of the cooling time of old white dwarfs. The cooling time of the star is calculated directly from the binding energy,

$$B(T) = -[\Omega(T) + U(T)], \qquad (7)$$

where

$$\Omega = -\int_0^{M_{\rm WD}} G\frac{m}{r}\,dm \quad \text{and} \quad U = \int_0^{M_{\rm WD}} u\,dm \qquad (8)$$

denote respectively the gravitational energy and the internal energy, derived from the EOS described in § 2. The crys-

›files for O (*top*) and ^{22}Ne (*bottom*) obtained either from the true phase diagrams (*dotted line* and *dashed line*, respectively) or from the
ıical fractionation at crystallization (*full line* and *dot-dashed line*, respectively). ^{56}Fe distribution is similar to ^{22}Ne distribution, with
$< 1.6 \times 10^{-3}$ and $X_{^{56}\rm Fe} = 0$ above, with the eutectic crystallization diagram. The curves labeled "MD" show the oxygen density profile with
thout (*dashed line*) chemical fractionation at crystallization when the initial C/O distribution is given by the stratified Mazitelli-D'Antona

Segretain et al. 1994

- Donor in 4U 1626-67 may be the remnant of a previously crystallized C-O WD
- HST UV spectra support this interpretation (Homer et al. 2002)
- Suggestive evidence that other LMXBs may have similar donors (Juett et al. 2001) (caution)